UNCLASSIFIED

AD NUMBER
AD866599
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 15 FEB 1970. Other requests shall be referred to Air Force Technical Applications Center, Patrick AFB, FL.**
AUTHORITY
AFTAC ltr 25 Jan 1972

THIS PAGE IS UNCLASSIFIED

TECHNICAL REPORT NO. 70-1

OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

Final Report, Project VT/9702,

Contract F33657-69-C-0803

1 January through 31 December 1969

NOTICE

THIS DOCUMENT IS SUBJECT TO SPECIAL EXPORT CONTROLS AND EACH TRANSMITTAL TO FOREIGN GOVERNMENTS OR FOREIGN NATIONALS MAY BE MADE ONLY WITH PRIOR APPROVAL OF CHIEF, AFTAC. /TSC

Alexandria, Va 22313

GEOTECH

A TELEDYNE COMPANY

TECHNICAL REPORT NO. 70-1

OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

Final Report, Project VT/9702
Contract F33657-69-C-0803
1 January through 31 December 1969

Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

TELEDYNE GEOTECH
3401 Shiloh Road
Garland, Texas

15 February 1970

IDENTIFICATION

AFTAC Project No:	VELA T/9702
Project Title:	Operation of TFSO
ARPA Order No:	624
ARPA Program Code No:	8F10
Name of Contractor:	Teledyne Industries, Geotech Division Garland, Texas
Contract Number:	F33657-69-C-0803
Effective Date of Contract:	1 January 1969
Amount of Contract:	$441,976
Contract Expiration Date:	31 December 1969
Program Manager:	B. B. Leichliter, BR1-2561, ext. 222

CONTENTS

CONTENTS, Continued

ILLUSTRATIONS

ILLUSTRATIONS, Continued

ILLUSTRATIONS, Continued

TABLES

ABSTRACT

This is a report of the work accomplished on Project VT/9702 from 1 January through 31 December 1969. Project VT/9702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes special research and test functions carried out at TFSO and research and development tasks performed by the Garland, Texas, staff using TFSO data.

BLANK PAGE

OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY
Final Report, Project VT/9702
Contract F33657-69-C-0803
1 January through 31 December 1969

1. INTRODUCTION

1.1 AUTHORITY

The research described in this report was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, and was monitored by the Air Force Technical Applications Center (AFTAC) under Contract AF 33657-69-C-0803, dated 1 January 1969. The statement of work for Project VT/9702 is included as appendix 1 to this report.

1.2 HISTORY

The Tonto Forest Seismological Observatory (TFSO), located near Payson, Arizona, was constructed by the United States Corps of Engineers in 1963. TFSO was designed to record seismic events and to be used as a laboratory for testing, comparing, and evaluating advanced seismograph equipment and recording techniques. The instrumentation was assembled, installed, and operated until 30 April 1965 by United Electrodynamics (UED) - now Earth Sciences, A Teledyne Company - under Contract AF 33(657)-7747. In March 1964, the Long-Range Seismic Measurements (LRSM) Program provided eight mobile seismic recording vans to extend the existing instrument arrays at TFSO. On 1 May 1965, Geotech assumed the responsibility for operating TFSO. The LRSM vans were phased out of the TFSO operation on 3 October 1965. During the 20-month period from 1 May 1965 through 31 December 1966, the operation of TFSO under Project VT/5055 was closely allied with the work performed at the Blue Mountains, Uinta Basin, and Wichita Mountains Seismological Observatories, under Projects VT/1124, VT/4054, and VT/5054. When reasonable, operating procedural changes, observatory instrumentation improvements, and special research investigations were accomplished simultaneously at all observatories. In other instances, improvements, modifications, and/or procedures that had been developed and proven at another observatory were incorporated into the TFSO operation. During 1967, under Contract AF 33657-67-C-0091, Project VT/7702, a 37-element, short-period array and a 7-element, long-period array were designed and installed.

1.3 WORK OF PROJECT VT/9702

The work of Project VT/9702 was to some degree a continuation of the work of earlier TFSO projects, and was similar to much of the work conducted at the Uinta Basin Seismological Observatory under Project VT/6705. The work of this project can be divided into the following general categories:

a. Continued operation of TFSO;

b. Evaluation and improvement of the standard instrumentation to provide a more efficient and effective observatory;

c. Field testing of newly developed and experimental instrumentation;

d. Analysis of resulting seismometric data;

e. Evaluation of the capabilities of the 37-element short-period and 7-element long-period arrays;

f. Short-period and long-period noise studies.

2. SUMMARY

Work at the Tonto Forest Seismological Observatory was directed primarily toward the continuous operation of four seismograph systems; the 37-element short-period array, the seven-element, three-component, long-period array, the broad-band vertical seismograph, and the crossed-linear, short-period array. Operating parameters of each seismograph system were maintained within specified tolerances and repairs were performed as required. All magnetic-tape and Develocorder film seismograms were shipped to the Seismic Data Laboratory, Alexandria, Virginia. Most were shipped directly, but unselected samples were routed through the Geotech laboratories at Garland, Texas, for quality control inspection.

Data taken during 1969 indicated that modifications made to the short-period array during 1968 caused a reduction of 60 percent in the lightning damage. Modifications made in June 1969 to the long-period array circuits reduced remote power supply damage to zero.

Seismometric data were routinely analyzed and earthquake phase arrival data were transmitted daily to the Environmental Science Services Administrations Coast and Geodetic Survey.

Operational tests and evaluation work was conducted with a high-frequency seismograph, an experimental Develocorder pump, a multichannel filter, and two high-magnification long-period seismographs. Nitrogen-filled long-period tank vaults were established and tested, and alternate arrangements of summed data for flag traces were studied.

Assistance was provided to personnel from four universities, one industrial organization, and one government agency who visited TFSO to test geophysical instrumentation.

3. OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

3.1 GENERAL

3.1.1 Security Inspection

Mr. K. G. Ozbolt, Industrial Security Inspector from the Phoenix, Arizona, office of the Los Angeles Defense Contract Adminstration Services Region (DCASR), conducted a routine security inspection during January 1969.

Mr. M. L. Craig, Industrial Security Chief, conducted routine inspections during May 1969 and September 1969. During each of these visits, the observatory procedures, methods, and facilities were found to be substantially in conformance with the requirements of the Department of Defense Industrial Security Manual.

3.1.2 Government Property Inspections

During August 1969, Mr. D. Peebles, Chief of the Production Division, and Mr. E. Friedman, Property Officer, both of the Phoenix office of Los Angeles DCASR, conducted a utilization survey of industrial plant equipment located at TFSO. This inspection was made at the request of DCASR, Dallas, Texas.

Several items were found that did not conform to DCASR standards. These discrepancies concerned methods for storage of materials and property, and the maintenance of Government vehicles. These discrepancies were corrected by changing TFSO procedures.

Mr. E. Friedman and Mr. W. Moore, newly assigned property officer for TFSO, made an orientation visit during early October.

In November, Mr. Friedman visited TFSO with Mr. Ray Madden in order to introduce Mr. Madden as the new TFSO property administrator, replacing Mr. Moore.

3.1.3 Routine Calibration of Test Equipment

Test instruments were routinely calibrated at TFSO during the year and calibration logs were maintained for all such instruments.

All calibrations are referred to Eppley standard cells which, in turn, are periodically certified to deviate less than 0.001 percent from standards maintained by the National Bureau of Standards.

3.1.4 Quality Control

3.1.4.1 Quality Control of 16-Millimeter Film Seismograms

Quality control checks of randomly selected 16-millimeter film seismograms from data trunks 1, 2, and 8, and the associated operation logs were made in Garland. Items that were routinely checked by the quality control analyst include:

a. Film boxes - neatness and completeness of box markings;

b. Develocorder logs - completeness, accuracy, and legibility of logs;

c. Film:

(1) Quality of the overall appearance of the record (for example, trace spacing and trace intensity);

(2) Quality of film processing;

d. Analysis - completeness, legibility, and accuracy of the analysis sheets.

Results of these evaluations are sent to the observatory for their review and comment.

3.1.4.2 Quality Control of FM Magnetic-Tape Seismograms

Routine quality control checks of randomly selected magnetic-tape seismograms were made in Garland and at TFSO to assure that recordings met specified standards. The following are among the items that were checked during quality control analysis:

a. Tape and box labeling;

b. Accuracy, completeness, and neatness of logs;

c. Adequate documentation of logs by voice comments on tape where applicable;

d. Seismograph polarity;

e. Level of calibration signals;

f. Relative phase shift between array seismographs;

g. Level of the microseismic background noise;

h. Level of the system noise;

i. PTA dc balance;

j. Oscillator alignment;

k. Quality of the recorded WWV signal where applicable;

l. Time-pulse carrier;

m. Binary coded digital time marks.

Discrepancies noted during quality-control analysis resulted in the adjustment of tape speed on four FM magnetic-tape recorders during the year.

3.1.4.3 Quality Control of Digital Magnetic-Tape Seismograms

Because of difficulties encountered in recovering data from some of the digital magnetic-tape seismograms we began routine checking of the quality of the Astrodata seismograms during June. Initially, one tape per day was checked, alternating between tapes recorded on transports 1 and 2; however, later we found

that checking of two or three seismograms each week was adequate to maintain good quality data. We found that routine quality control analysis of digital seismograms was valuable in helping to detect Astrodata system malfunctions, format errors, and systematic operator errors which might otherwise have gone undetected for extended periods. Also, quality control efforts were successful in improving the accuracy of the operating logs and in delineating areas where system modifications could improve the system performance.

Among those characteristics of the digital seismograms that we routinely check are:

a. Presence or absence of parity errors;

b. Recording sensitivity;

c. Fidelity of reproductions;

d. Quality of x-y plots of short intervals of data from each channel;

e. Presence of header record and correct record length;

f. Accuracy, completeness, and neatness of the associated logs.

3.2 SEISMOGRAPH SYSTEMS OPERATED DURING PROJECT VT/9702

3.2.1 Crossed-Linear Array

The crossed-linear array, consisting of 12 short-period three-component elements spaced at intervals of about 2 kilometers was operated throughout Project VT/9702. A summation of eight of the vertical components of elements of this array was used as a flag trace during routine on-line seismogram analysis. The configuration of this array is shown in figure 1 and its orientation in relation to the other TFSO arrays is shown in figure 2.

3.2.2 Thirty-Seven Element Array

A 37-element array of short-period vertical seismographs (figure 2) was installed under Project VT/7702. Under Project VT/8702, this array was evaluated from the standpoint of reliability, beam-steering capability, and detection capability. Operation of this array continued under VT/9702.

3.2.3 Seven-Element Array of Three-Component Long-Period Seismographs

A seven-element array of three-component long-period seismographs was installed during Project VT/7702. Under Project VT/8702, operational difficulties were experienced with seismographs in this array and the major efforts were directed toward solving these problems. Some modifications and changes were made to the seismographs and its operation was continued during Project VT/9702. The configuration of this array is also shown in figure 2.

3.2.4 Broad-Band Seismograph

Operation of the vertical broad-band seismograph was resumed on 21 May 1969.

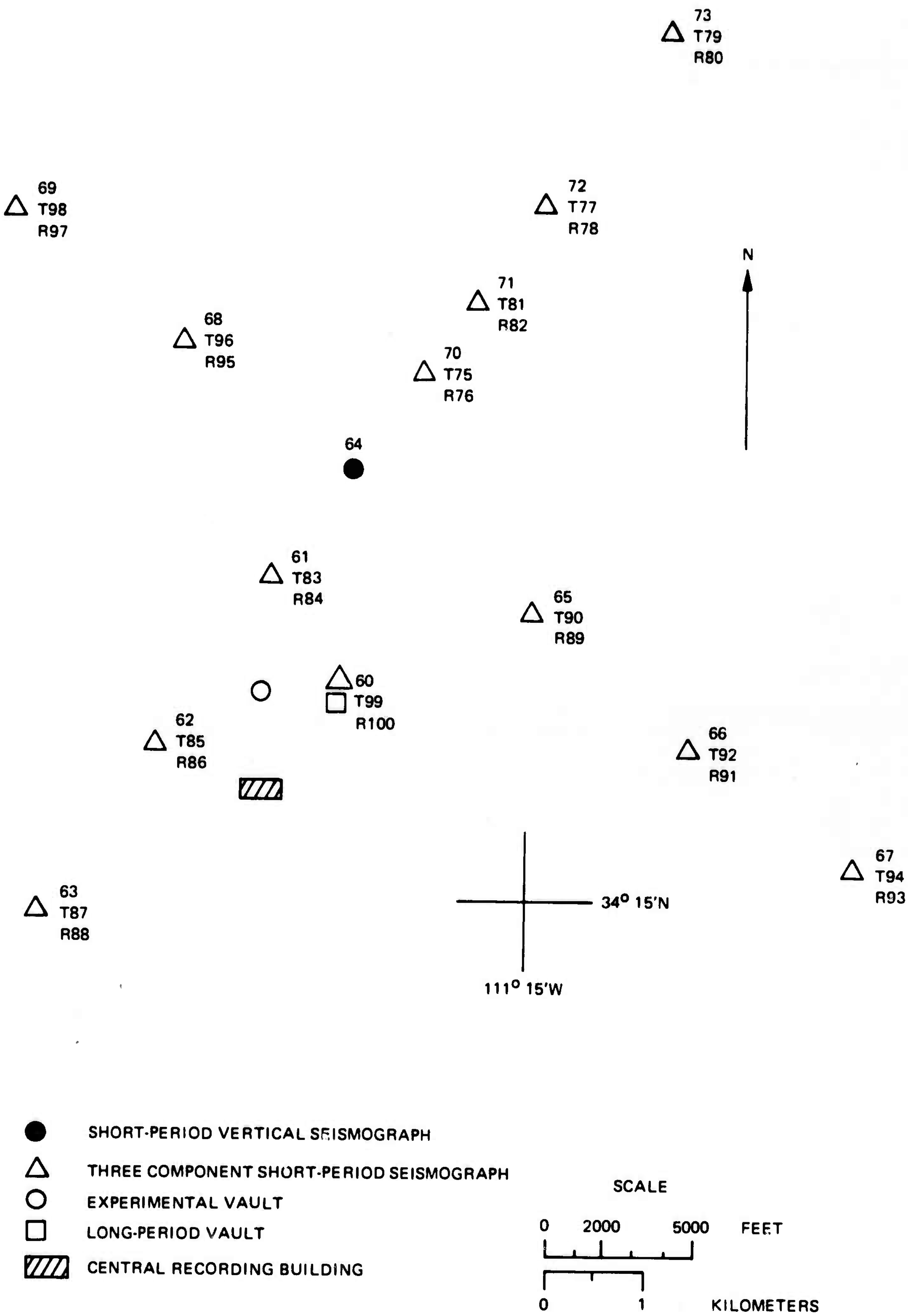


Figure 1. Configuration of the crossed-linear array of short-period seismographs at TFSO

G 4698

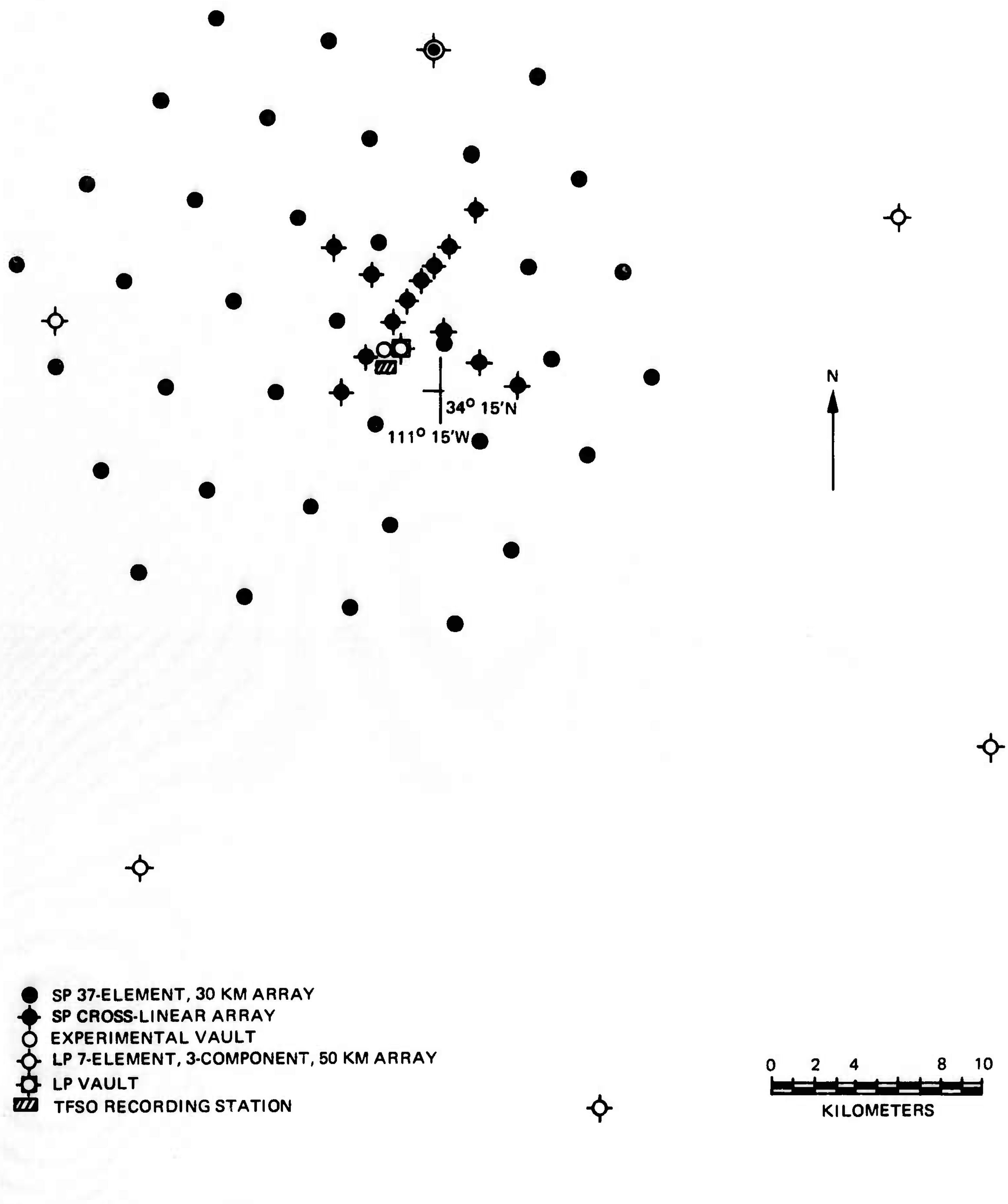


Figure 2. Vault locations in the 37-element, short-period array, the 7-element, long-period array, and the crossed-linear array at TFSO

G 4699

This seismograph uses a seismometer installed in the LP1 vault and a phototube amplifier installed in the CRB, and has the frequency response shown in figure 3.

3.3 STANDARD SEISMOGRAPH OPERATING PARAMETERS

The operating parameters and tolerances for the TFSO standard seismographs are shown in table 1. Frequency response tests are made monthly, and the parameters of seismograph systems not conforming to the tolerances shown in table 2 are reset.

Normalized response characteristics of TFSO standard seismographs are shown in figure 3. In addition to these standard seismographs, two filtered summation seismographs and a high-frequency seismograph were recorded. A resistive summation of eight selected elements of the crossed-linear array was filtered by each of two band-pass filters having different characteristics. One of the filtered seismographs (ΣTF) utilized a filter with a high-cut frequency of 1.75 cps and a low-cut frequency of 0.7 cps, both with slopes of 12 dB per octave. The other filtered seismograph (ΣTFK) used a filter with the high-cut and low-cut frequencies set at 2.0 cps and 1.0 cps, respectively, with slopes of 24 dB per octave. Both of these seismographs are recorded on 16-millimeter film.

3.4 DATA CHANNEL ASSIGNMENTS

Each data format recorded at TFSO was assigned a number (format number in the case of digital seismograms), and each time a new data format was established a new number was assigned. Data format change notices showing both the new data channel assignments and the previous data channel assignments were submitted to the Project Officer and were distributed to frequent users of TFSO data. The data formats recorded during Project VT/9702 are summarized in tables 3 and 4, and a key to the seismograph designators is given in table 5.

3.5 OPERATION OF THE ASTRODATA SEISMIC DATA ACQUISITION SYSTEM

From 1 January 1969 through 31 December 1969, the Astrodata Seismic Data Acquisition System (ASDAS) was operated daily from 0000Z to approximately 2200Z. The time from approximately 2200Z to 2400Z was used for system test, adjustment, and maintenance. Emergency maintenance was performed at other times, when parts such as vacuum pump motors failed and stopped operation of the ASDAS. These failures, in general, caused losses of data for short periods of time, usually not more than 2 hours. A more serious failure was caused by a head misalignment on transport #1. This was first detected on 2 December, and was corrected on 11 December, but resulted in the loss of data from 24 November 1969 to 11 December 1969. Tape head alignment is now checked monthly on both ASDAS tape transports.

Some tapes which are received for use on the ASDAS are defective, having been damaged by mishandling or by operation on misaligned transports. To avoid loss of data, all tapes are inspected for wrinkles and scratches before they are used. This procedure has been highly successful. To date, 297 suspect tapes - mostly

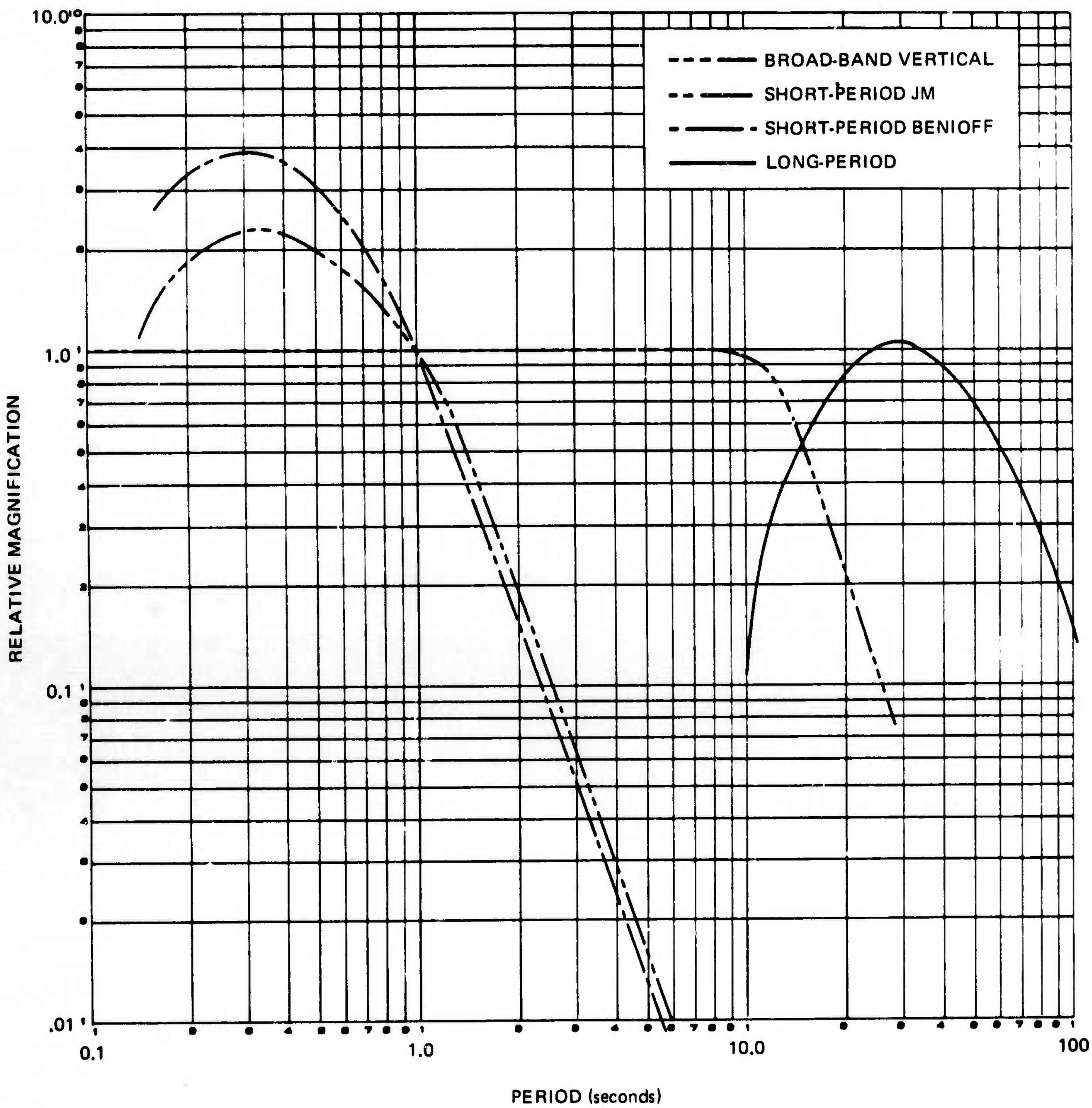


Figure 3. Response characteristics of TFSO standard seismographs normalized at a period of one second

G 5486

Table 1. Operating parameters and tolerances of standard seismographs at TFSO

Seismograph				Operating parameters and tolerances				Filter settings		
System	Comp	Type	Model	Ts	λs	Tg	λg	Model	Bandpass at 3 dB cutoff (sec)	Cutoff rate at SP side (dB/oct)
SP[a]	Z	Johnson-Matheson	6480	1.25 ±2%	0.54 ±5%	---	---	2888-1	0.2 - 1.0	6
SP[b]	Z	Johnson-Matheson	6480	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	6824-1	0.1 - 100	12
SP[b]	H	Johnson-Matheson	7515	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	6824-1	0.1 - 100	12
SP	Z	Benioff	1051	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	6824-1	0.1 - 100	12
SP	H	Benioff	1101	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	6824-1	0.1 - 100	12
SP	Z	UA Benioff	1051	1.0 ±2%	1.0 ±5%	0.75 ±5%	1.0 ±5%	---	---	--
SP[c]	H	UA Benioff	1101	1.0 ±2%	1.0 ±5%	0.75 ±5%	1.0 ±5%	---	---	--
SP[c]	H	Wood-Anderson	TS 220	0.8	0.78	---	---	---	---	--
BB	Z	Press-Ewing	SV-282	12.5 ±5%	0.45 ±5%	0.64 ±5%	9.0 ±5%	6824-7	0.05- 100	12
LP	Z	Geotech	7505A	20.0 ±5%	0.77	---	---	30024	80 - 300	6
LP	H	Geotech	8700C	20.0 ±5%	0.77	---	---	30024	80 - 300	6

KEY

SP Short period
IB Intermediate band
LP Long period
UA Unamplified (i.e., earth powered)

Ts Seismometer free period (sec)
Tg Galvanometer free period (sec)
λs Seismometer damping constant
λg Galvanometer damping constant

[a]37-element hexagonal array

[b]Linear array and 3 comp

[c]Discontinued after 18 Nov

Table 2. TFSO frequency response norms and tolerances

Short period

T (sec)	f (cps)	Tolerance (percent)	Relative amplitude Norm	Max	Min
5.0	0.2	10	0.0118	0.013	0.0106
2.5	0.4	7.8	0.0988	0.106	0.0916
1.25	0.8	5.0	0.68	0.714	0.646
1.00	1.0	0	1.00	1.00	1.00
0.67	1.5	5.2	1.55	1.63	1.47
0.50	2.0	5.1	1.97	2.07	1.87
0.33	3.0	7.3	2.30	2.47	2.13
0.25	4.0	12.2	2.05	2.30	1.80
0.167	6.0	20.3	1.38	1.66	1.10

Long period

T (sec)	f (cps)	Tolerance (percent)	Relative amplitude Norm	Max	Min
100	0.01	20	0.135	0.162	0.108
80	0.0125	20	0.278	0.333	0.222
60	0.0167	15	0.485	0.558	0.412
50	0.02	15	0.644	0.741	0.548
40	0.025	10	0.874	0.961	0.787
30	0.033	5	1.03	1.082	0.978
25	0.04	0	1.00	1.00	1.000
20	0.05	5	0.825	0.866	0.784
15	0.0667	10	0.470	0.517	0.423
10	0.1	20	0.110	0.132	0.0879

Table 3. Data channel assignments for TFSO 16-millimeter film seismograms made during Project VT/9702. Dates without asterisks are start dates; dates with asterisks are stop dates

DEVELOCORDERS
Fast speed, 30 mm/minute

Channel	Data group 7240 14 Nov 67	Data group 7242 15 Nov 67	Data group 7254 7 Feb 68	Data group 7255 7 Feb 68 11 Feb 69*	Data group 7262 26 Mar 68 5 Feb 69* 29 Jul 69	Data group 7263 26 Mar 68
1	TCDMG	TCDMG	TCDMG	TCDMG	TCDMG	TCDMG
2	Z 1	Z 15	Z 72	T 72	T 63	Z 29
3	Z 2	Z 16	Z 68	T 68	T 66	Z 30
4	Z 3	Z 17	Z 62	T 62	T 67	Z 31
5	Z 4	Z 18	Z 65	T 65	T 69	Z 32
6	Z 5	Z 19	Z 71	T 71	T 73	Z 33
7	Z 6	Z 20	Z 70	T 70	R 73	Z 34
8	Z 7	Z 21	Z 64	T 61	R 69	Z 35
9	Z 8	Z 22	Z 61	R 72	R 67	Z 36
10	Z 9	Z 23	Σ T	R 68	R 66	Z 37
11	Z 10	Z 24	Σ TF	R 62	R 63	MS
12	Z 11	Z 25	Σ TFK	R 65	Z47BF	Wi
13	Z 12	Z 26	Z 60	R 71	N47BF	Σ T
14	Z 13	Z 27	N60SP	R 70	E47BF	Z 69
15	Z 14	Z 28	E60SP	R 61	WWV	Z 73
16	WWV	WWV	WWV	WWV		WWV

Table 3, Continued

Develocorders, fast speed, 30 mm/min, continued

Channel	Data group 7271 25 June 68	Data group 7273 22 Dec 68 24 Jan 69*	Data group 7278 28 Jan 69	Data group 7279 5 Feb 69 19 Mar 69*	Data group 7280 12 Feb 69 2 Apr 69* 22 Jul 69	Data group 7281 20 Mar 69 28 Jul 69*	Data group 7283 2 Apr 69 22 Jul 69*
1	TCDMG	BSO-19PT	BS 0	TCDMG	TCDMG	TCDMG	TCDMG
2	Z 63	BSO-35PT	BS 1	Σ T	T 72	Σ T	Z 72
3	Z 66	BS2-19PT	BS 3	Σ X	T 68	Σ X	Z 68
4	Z60LL	BS2-35PT	BS 4	Σ TF	T 62	Σ TF	Z 62
5	N60LL	BS1-35PT	BS 9	Σ TFK	T 65	Σ TFK	Z 65
6	E60LL	BS3-35PT	Σ TFK	Σ XF	T 71	Σ XFK	Z 71
7	MS	Σ TF	Z 60	Σ NWF	T 70	Σ NWF	Z 70
8	Z47BF	Z 60	WWV	Σ NEF	T 61	Σ NEF	T 61
9	ZHF-8	WWV		Σ EWF	R 72	Σ EWF	R 72
10	ZHF-1/10			WWV	R 68	WWV	R 68
11	BFV				R 62		R 62
12	Z60SL				R 65		R 65
13	N60SL				MCF 1		MCFLP
14	E60SL				MCF 2		WWV
15	Wi				MCFPR		
16	WWV				WWV		

Table 3, Continued

DEVELOCORDERS
Slow speed, 6 mm/minute

Channel	Data group 7253 18 Dec 67 20 Jan 69* 26 Jul 69 6 Aug 69*	Data group 7267 25 May 68 22 Jan 69*	Data group 7268 25 May 68 22 Jan 69*	Data group 7269 25 May 68 22 Jan 69*	Data group 7274 21 Jan 69 24 Apr 69*	Data group 7275 23 Jan 69 1 Apr 69* 23 Jul 69 25 Jul 69*
1	TCDMG	Z2LP	Z4LP	Z6LP	TCDMG	Z2LP
2	ML	N2LP	N4LP	N6LP	ML	N2LP
3	Z1LP	E2LP	E4LP	E6LP	Z1LP	E2LP
4	N1LP	Z3LP	Z5LP	Z7LP	N1LP	Z3LP
5	E1LP	N3LP	N5LP	N7LP	E1LP	N3LP
6	MS	E3LP	E5LP	E7LP	MS	E3LP
7	Z1LL	Σ ZLP	Σ ZLP	Σ ZLP	Σ ZLP	ML
8	N1LL	ML	ML	ML	Z1LL	Wi
9	E1LL	Wi	Wi	Wi	N1LL	WWV
10	Wi	WWV	WWV	WWV	E1LL	
11	WWV				Wi	
12					WWV	
13						
14						
15						
16						

Table 3, Continued

Develocorders, slow speed, 6 mm/minute, continued

Channel	Data group 7276 23 Jan 69	Data group 7277 23 Jan 69 20 May 69*	Data group 7282 2 Apr 69 22 Jul 69*	Data group 7284 25 Apr 69 25 Jul 69*	Data group 7285 21 May 69	Data group 7286 26 July 69
1	Z4LP	Z6LP	MCFLP	TCDMG	Z6LP	Z2LP
2	N4LP	N6LP	Z2LP	ML	N6LP	N2LP
3	E4LP	E6LP	N2LP	Z1LP	E6LP	E2LP
4	Z5LP	Z7LP	E2LP	N1LP	Z7LP	Z3LP
5	N5LP	N7LP	Z3LP	E1LP	N7LP	E3LP
6	E5LP	E7LP	N3LP	EXLP	E7LP	N3LP
7	ML	ML	E3LP	MS	Z39BB	Σ ZLP
8	Wi	Wi	ML	Σ ZLP	ML	ML
9	WWV	WWV	Wi	Z1LL	Wi	Wi
10			WWV	N1LL	WWV	WWV
11				E1LL		
12				WWV		
13						
14						
15						
16						

Table 3, Continued

Develocorders, slow speed, 6 mm/minute, continued

Channel	Data group 7287 7 Aug 69 18 Aug 69* 20 Sept 69 9 Oct 69*	Data group 7287** 10 Oct 69
1	TCDMG	TCDMG
2	ML	ML
3	Z1LP	E1LP
4	N1LP	N1LP
5	E1LP	Z1LP
6	ZXLP	ZXLP
7	ZYLP	ZYLP
8	MS	MS
9	Z1LL	Z1LL
10	N1LL	N1LL
11	E1LL	E1LL
12	Wi	Wi
13	WWV	WWV
14		
15		
16		

**Data trace positions changed, data group number not changed.

Table 4. Data channel assignment for TFSO FM magnetic-tape seismograms made during Project VT/9702. Dates without asterisks are start dates; dates with asterisks are stop dates

TAPE RECORDERS

Channel	Data group 7239 16 Nov 67	Data group 7241 15 Nov 67	Data group 7244 15 Nov 67	Data group 7259 7 Feb 67 10 Sept 69*	Data group 7265 25 May 68	Data group 7270 25 June 68	Data group 7289 11 Sept 69
1	TCDMG	TCDMG	TCDMG	TCDMG	TCDMG	TCDMG	TCDMG
2	Z 1	Z 13	Z 25	Z1LP	Z1LP	Z5LP	Z1LP
3	Z 2	Z 14	Z 26	N1LP	N1LP	N5LP	ZYLP
4	Z 3	Z 15	Z 27	E1LP	E1LP	E5LP	ZXLP
5	Z 4	Z 16	Z 28	Σ T	Z2LP	Z6LP	Σ T
6	Z 5	Z 17	Z 29	BFV	N2LP	N6LP	BFV
7	Comp.	Comp.	Comp.	Comp.	Comp.	Comp.	Comp.
8	Z 6	Z 18	Z 30	Z 60	E2LP	E6LP	Z 60
9	Z 7	Z 19	Z 31	E60SP	Z3LP	Z7LP	E60SP
10	Z 8	Z 20	Z 32	N60SP	N3LP	N7LP	N60SP
11	Z 9	Z 21	Z 33	Z60LL	E3LP	E7LP	Z60LL
12	Z 10	Z 22	Z 34	E60LL	Z4LP	Σ ZLP	E60LL
13	Z 11	Z 23	Z 35	N60LL	N4LP	ZHF-8	N60LL
14	Z 12	Z 24	Z 36	WWV	E4LP	Z 37	WWV

Table 5. Key to the designations used in the data format assignments at TFSO

TCDMG	Time Code Data Management Generator
Z	Amplified vertical seismograph from site identified by number
ΣT	Summation of the crossed-linear array vertical seismographs
ΣTF	ΣT filtered (UED filter)
ΣTFK	ΣT filtered (Krohn-Hite)
N	North-south horizontal seismograph
E	East-west horizontal seismograph
SP	Short-period seismograph
WWV	Radio time from National Bureau of Standards Radio Station WWV (WWV, STS, and Voice on tape)
T	Transverse seismograph
R	Radial seismograph
BF	Seismograph using Benioff seismometer
LL	Low, low magnification (short-period) or low magnification long-period seismograph
MS	Short-period microbarograph
IB	Intermediate-band seismograph
V	Unamplified (earth-powered) vertical seismograph
SL	Low magnification short-period seismograph
WI	Wind indicator
BS	Beam-steered seismograph. Number refers to azimuth orientation.
HF8	High-frequency seismograph (suffix "1/10" indicates magnification one-tenth that of ZHF8 seismograph)
PT	Number of points used in digital filters (beam-steer)
LP	Long-period seismograph from site identified by number
BB	Broad band seismograph from site identified by number
ΣB	Summation of R-70, -61, -65, -68 seismographs
ΣC	Summation of T-70, -61, -65, -68 seismographs
COMP	Tape recorder wow and flutter compensation channel

with wrinkled edges - have been found and removed from use. These were shipped to SDL where they were tested operationally. SDL found two-thirds of the suspect tapes were defective. Table 6 lists the formats in which digital data were recorded during 1969.

3.6 SHIPMENT OF DATA TO SDL

Six analog FM magnetic-tape units are used to record data for the AFTAC/VELA Seismological Center (VSC). Tapes from these units are sent weekly to our Garland, Texas, laboratory for quality control, and are shipped from Garland to SDL about 15 days after the end of the month in which they were recorded.

All Develocorder film seismograms except quality control copies are routinely shipped to SDL. One seismogram from each Develocorder is sent each week to the Garland, Texas, laboratory for quality control. These recordings are sent to SDL by the Garland office at a later date.

Until April, all digital magnetic-tape seismograms were held at the observatory until they were requested. If no request was received, the tapes were recycled on a 6-week schedule. During April, we began making daily shipments to SDL of all digital tapes except two per week which were sent to the Garland Laboratory for quality control. These tapes were sent to SDL by the Garland facility at a later date.

3.7 FACILITIES AND EQUIPMENT

3.7.1 Facilities Maintenance

Lightning storms were severe during July, August, and September 1969. During this interval, two trees within 100 feet of the CRB were struck, a 20,000-volt Arizona Public Service transformer located near the parking lot was damaged, and the CRB was struck. Lightning caused major damage to six starter coils and six switches in the water well and pump building.

The TFSO facilities were maintained in accordance with sound industrial procedures throughout the reporting period. Work in this area included periodic extermination service, semiannual fire extinguisher inspection, routine cleaning, inspection of all office equipment, and periodic servicing and maintenance of all air conditioning and heating facilities.

During October the circuit breaker for the standby power generator failed and dropped out whenever the full TFSO load was applied to the generator. For 2 weeks, until a new breaker was installed, the generator was operated only at reduced load and was used only to furnish standby power to the CRB.

3.7.2 Equipment Maintenance

3.7.2.1 Spiral-Four Cable Replacement

During 1969, several lengths of Spiral-4 cable were replaced in the long- and short-period arrays. In general, replacement of the cable was required because

Table 6. ASDAS recording format used at TFSO

1 January 1969 through 5 March 1969

Format No. 13

Channel	Data	Channel	Data
1	Z1LP	25	Z4LPLo
2	Z2LP	26	Z5LPLo
3	Z3LP	27	Z6LPLo
4	Z4LP	28	Z7LPLo
5	Z5LP	29	N1LPLo
6	Z6LP	30	N2LPLo
7	Z7LP	31	N3LPLo
8	N1LP	32	N4LPLo
9	N2LP	33	N5LPLo
10	N3LP	34	N6LPLo
11	N4LP	35	N7LPLo
12	N5LP	36	E1LPLo
13	N6LP	37	E2LPLo
14	N7LP	38	E3LPLo
15	E1LP	39	E4LPLo
16	E2LP	40	E5LPLo
17	E3LP	41	E6LPLo
18	E4LP	42	E7LPLo
19	E5LP	43	Z60SP
20	E6LP	44	N60SP
21	E7LP	45	E60SP
22	Z1LPLo	46	Σ LPZ
23	Z2LPLo	47	WWV
24	Z3LPLo	48	STS

Table 6, Continued

6 March 1969 through 2 April 1969

Format No. 12

Channel	Data	Channel	Data
1	Z 1	25	Z 25
2	Z 2	26	Z 26
3	Z 3	27	Z 27
4	Z 4	28	Z 28
5	Z 5	29	Z 29
6	Z 6	30	Z 30
7	Z 7	31	Z 31
8	Z 8	32	Z 32
9	Z 9	33	Z 33
10	Z 10	34	Z 34
11	Z 11	35	Z 35
12	Z 12	36	Z 36
13	Z 13	37	Z 37
14	Z 14	38	Z1LP
15	Z 15	39	Z2LP
16	Z 16	40	Z3LP
17	Z 17	41	Z4LP
18	Z 18	42	Z5LP
19	Z 19	43	Z6LP
20	Z 20	44	Z7LP
21	Z 21	45	Σ T
22	Z 22	46	Σ LPZ
23	Z 23	47	WWV
24	Z 24	48	STS

Table 6, Continued

3 April 1969 through 9 April 1969

Format No. 15

Channel	Data	Channel	Data
1	Z1LP	25	Z 4
2	Z2LP	26	Z 5
3	Z3LP	27	Z 6
4	Z4LP	28	Z 7
5	Z5LP	29	Z 8
6	Z6LP	30	Z 9
7	Z7LP	31	Z 10
8	N1LP	32	Z 11
9	N2LP	33	Z 12
10	N3LP	34	Z 13
11	N4LP	35	Z 14
12	N5LP	36	Z 15
13	N6LP	37	Z 16
14	N7LP	38	Z 17
15	E1LP	39	Z 18
16	E2LP	40	Z 19
17	E3LP	41	Σ T
18	E4LP	42	Z 60
19	E5LP	43	N60SP
20	E6LP	44	E60SP
21	E7LP	45	BS 0
22	Z 1	46	BS 1
23	Z 2	47	WWV
24	Z 3	48	STS

Table 6, Continued

10 April 1969 through 25 September 1969

Format No. 16

Channel	Data	Channel	Data
1	Z1LP	25	Z 4
2	Z2LP	26	Z 5
3	Z3LP	27	Z 6
4	Z4LP	28	Z 7
5	Z5LP	29	Z 8
6	Z6LP	30	Z 9
7	Z7LP	31	Z 10
8	N1LP	32	Z 11
9	N2LP	33	Z 12
10	N3LP	34	Z 13
11	N4LP	35	Z 14
12	N5LP	36	Z 15
13	N6LP	37	Z 16
14	N7LP	38	Z 17
15	E1LP	39	Z 18
16	E2LP	40	Z 19
17	E3LP	41	Σ T
18	E4LP	42	Z 60
19	E5LP	43	N60SP
20	E6LP	44	E60SP
21	E7LP	45	ZHF-8
22	Z 1	46	BS 1
23	Z 2	47	WWV
24	Z 3	48	STS

Table 6, Continued

26 September 1969 through 3 November 1969

Format No. 17

Channel	Data	Channel	Data
1	Z 1	25	Z 25
2	Z 2	26	Z 26
3	Z 3	27	Z 27
4	Z 4	28	Z 28
5	Z 5	29	Z 29
6	Z 6	30	Z 30
7	Z 7	31	Z 31
8	Z 8	32	Z 32
9	Z 9	33	Z 33
10	Z 10	34	Z 34
11	Z 11	35	Z 35
12	Z 12	36	Z 36
13	Z 13	37	Z 37
14	Z 14	38	Z1LP
15	Z 15	39	Z2LP
16	Z 16	40	Z3LP
17	Z 17	41	Z4LP
18	Z 18	42	Z5LP
19	Z 19	43	Z6LP
20	Z 20	44	Z7LP
21	Z 21	45	ZXLP
22	Z 22	46	ZYLP
23	Z 23	47	Σ T
24	Z 24	48	STS

Table 6, Continued

3 November 1969 through 31 December 1969

Format No. 18

Channel	Data	Channel	Data
1	Z 1	25	Z 25
2	Z 2	26	Z 26
3	Z 3	27	Z 27
4	Z 4	28	Z 28
5	Z 5	29	Z 29
6	Z 6	30	Z 30
7	Z 7	31	Z 31
8	Z 8	32	Z 32
9	Z 9	33	Z 33
10	Z 10	34	Z 34
11	Z 11	35	Z 35
12	Z 12	36	Z 36
13	Z 13	37	Z 37
14	Z 14	38	Z1LP
15	Z 15	39	Z2LP
16	Z 16	40	Z3LP
17	Z 17	41	Z4LP
18	Z 18	42	Z5LP
19	Z 19	43	Z6LP
20	Z 20	44	Z7LP
21	Z 21	45	ZXLP
22	Z 22	46	ZHF-8
23	Z 23	47	Σ T
24	Z 24	48	STS

of excessive leakage-to-ground, lightning damage, or vandalism. Spiral-4 cable replacement history is summarized in table 7.

Table 7. Summary of Spiral-4 cable replacements in 1969

Month	Number of reels replaced (1/4-mile lengths)	Reason for replacement
January	17	Line leakage
February	11	Line leakage
March	16	Line leakage
April	4	Line leakage
May	4	Line leakage and lightning
June	4	Line leakage
July	4	Lightning
August	11	Line leakage and lightning
September	4	Line leakage and lightning
October	16	Line leakage and lightning
November	19	Line leakage and lightning
December	11	Line leakage
TOTAL	121	

Spiral-4 cables that were cleanly cut were spliced and sealed rather than replaced. Spiral-4 cable splice history is summarized in table 8.

Of 9 cables damaged by vandalism, 7 were shot and 2 were cut with an ax. Although the FBI, Phoenix, Arizona, investigated the shooting of one cable, collected evidence, and instituted prosecution proceedings, the case was dismissed when the Court ruled that insufficient evidence was available to justify a trial.

Ten cables were damaged by a United States Forest Service subcontractor who was doing rehabilitation work within the 37-element array. Five other cables were damaged by county maintenance equipment.

During December, two thousand reels of Spiral-4 cable were delivered to the observatory. Several sections of cable were used and other sections randomly checked. All cable checked and used was found to be in good condition.

Table 8. Summary of Spiral-4 cable splices in 1969

Month	Number of splices	Reason for splices
January	2	Unknown vehicle
February	2	Unknown vehicle
March	0	
April	4	Road maintenance
May	2	Road maintenance & vandalism
June	4	Road maintenance & fire
July	2	Vandalism
August	0	
September	0	
October	11	Road Maintenance, vandalism, fire, and animal
November	6	Road maintenance, vandalism, vehicle, and animal
December	1	Road maintenance
TOTAL	34	

3.7.2.2 Phase Responses

The phase responses of all channels in the 37-element short-period array were measured in April, May, June, and December and were maintained to a tolerance of ±4.5 degrees at 1.0 cps.

3.7.2.3 Seismometer Motor-Constant Checks

The annual motor constant (G) checks of the 37-element, short-period array and 7-element, three-component, long-period array seismometers were made between 17 September and 7 November. The results of these checks and adjustments that were made are shown in table 9.

3.7.2.4 Tape Speed Checks

The tape speeds on all FM magnetic-tape recorder transports are checked once per month at TFSO and are maintained at 0.3 inch per second ±0.5 percent. In addition, this tape speed is monitored during routine quality control examinations conducted on selected tapes at Garland.

3.8 EMERGENCY POWER GENERATOR

The 100 kW generator, Diesel Power Unit, Caterpillar Model 59825, was operated a total of 137.6 hours. It furnished power for 99 hours during lightning storms and commercial power outages, and was operated 38.6 hours for test and preventative maintenance.

Table 9. 1969 annual 37-element short-period array and 7-element 3-component long-period array seismometer motor constant checks

Short-Period Array

Channel	Initial G (newtons/ ampere)	Percent error from .296 (newtons/ ampere)	Final G (newtons/ ampere)	Remarks
Z 1	0.285	3.7	0.291	Degaussed in field
Z 2	0.289	2.4	0.302	Degaussed in field
Z 3	0.288	2.7	0.303	Degaussed in field
Z 4	0.275	7.1	0.296	Degaussed in field and G resistor changed
Z 5	0.303	2.4	0.300	Degaussed in field
Z 6	0.292	1.3	0.292	
Z 7	0.290	2.0	0.295	Degaussed in field
Z 8	0.300	1.3	0.300	
Z 9	0.280	5.4	0.300	Adjusted in shop
Z 10	0.306	3.4	0.296	
Z 11	0.298	0.7	0.298	
Z 12	0.292	1.3	0.292	
Z 13	0.296	0.0	0.296	
Z 14	0.298	0.7	0.298	
Z 15	0.304	2.7	0.292	Degaussed in field and G resistor changed
Z 16	0.293	1.0	0.293	
Z 17	0.298	4.7	0.299	Adjusted in shop
Z 18	0.294	0.7	0.294	
Z 19	0.289	2.4	0.290	Degaussed in field
Z 20	0.291	1.7	0.291	
Z 21	0.292	1.3	0.292	
Z 22	0.266	10.1	0.305	G resistor changed
Z 23	0.294	0.7	0.294	
Z 24	0.296	0.0	0.296	
Z 25	0.292	1.3	0.292	
Z 26	0.296	0.0	0.296	
Z 27	0.286	3.4	0.293	Degaussed in field and G resistor changed

Table 9, Continued

Short-Period Array

Channel	Initial G (newtons/ ampere)	Percent error from .296 (newtons/ ampere)	Final G (newtons/ ampere)	Remarks
Z 28	0.285	3.7	0.297	Degaussed in field and G resistor changed
Z 29	0.298	0.7	0.298	
Z 30	0.291	1.7	0.296	
Z 31	0.282	4.7	0.297	Degaussed in field
Z 32	0.293	1.0	0.293	
Z 33	0.298	0.7	0.298	
Z 34	0.297	0.3	0.297	
Z 35	0.294	0.7	0.294	
Z 36	0.280	5.4	0.300	Degaussed in field
Z 37	0.304	2.7	0.304	

Long-Period Array

Channel	Initial G (newtons/ ampere)	Percent error from .0280 (newtons/ ampere)	Final G (newtons/ ampere)	Remarks
Z1LP	0.0289	3.2	0.0289	
N1LP	0.0277	1.1	0.0277	
E1LP	0.0284	1.4	0.0284	
Z2LP	0.0276	1.4	0.0276	
N2LP	0.0286	2.1	0.0286	
E2LP	0.0276	1.4	0.0276	
Z3LP	0.0246	12.0	0.0271	Shunts removed
N3LP	0.0275	1.8	0.0275	
E3LP	0.0260	7.0	0.0284	Shunts removed
Z4LP	0.0283	1.1	0.0283	
N4LP	0.0276	1.4	0.0276	
E4LP	0.0279	0.4	0.0279	
Z5LP	0.0246	12.0	0.0286	Installed high Z cal coil
N5LP	0.0276	1.4	0.0276	Shunts removed
E5LP	0.0324	15.7	0.0274	Shunts removed

Table 9, Continued

Long-Period Array

Channel	Initial G (newtons/ ampere)	Percent error from .0280 (newtons/ ampere)	Final G (newtons/ ampere)	Remarks
Z6LP	0.0274	2.1	0.0274	
N6LP	0.0313	11.8	0.0280	Corrected in CRB
E6LP	0.0276	1.4	0.0276	
Z7LP	0.0273	2.5	0.0273	
N7LP	0.0280	0.0	0.0280	
E7LP	0.0280	0.0	0.0280	
ZYLP	0.0051	-	0.0051	
ZXLP	0.0310	-	0.0310	
EXLP	0.0276	-	0.0276	

4. MAINTENANCE AND MODIFICATION OF TFSO INSTRUMENTATION

4.1 SHORT-PERIOD ARRAY

4.1.1 Lightning Protection

No modifications were made to the lightning protection circuits of the short-period array during 1969, but data were collected to permit evaluation of the present circuits.

From 1 January to 31 December 1968, electrical storms occurred during 38 days and damaged 42 amplifiers. During the same time period in 1969, electrical storms occurred during 58 days and damaged 25 amplifiers. With corrections made for storm incidence, the relative damage during 1969 was 39 percent of that during 1968. This indicates that a substantial improvement in the effectiveness of the lightning protection circuits was realized by modifications undertaken during the latter part of 1968.

4.1.2 Spike Noise

TFSO records have continued to be free of spikes since the circuits were modified to transmit dc power and FM signals over separate cable pairs last September and October. However, to reconfirm that spikes occurred when dc power and FM signal were on the same cable pair, Z66, a linear array channel, was connected to instrumentation and circuitry like that used in the 37-element array prior to the modifications made in September and October 1968. Z66 operated under this test condition from 10 January through 13 March 1969. During this time period, Z66 recorded many spikes, whereas the seismographs in the 37-element array were free from spikes during the same interval. Figures 4, 5, 6, and 7 show seismograms for Z66 and Z1 through Z37 for 1113Z on 14 February. Note the spikes on Z66 and the freedom of spikes on Z1 through Z37.

4.1.3 Solid-State Amplifiers

Amplifier modification work was continued throughout the report period. Whenever an amplifier is brought in from the field, one resistor is changed to increase its output carrier level. To date, 32 of the 43 amplifiers have been modified.

4.2 LONG-PERIOD ARRAY

4.2.1 Lightning Protection

Following the frequent failure of fuses in the circuits protecting the remote Lambda power supplies, and following the loss of seven seismic amplifiers due to lightning in May, additional lightning protection was designed and was installed throughout the array during June. Figures 8 and 9 show the circuit modifications that were made. The protection afforded by these circuits has been completely effective. No Lambda power supplies have been damaged since these modifications were made.

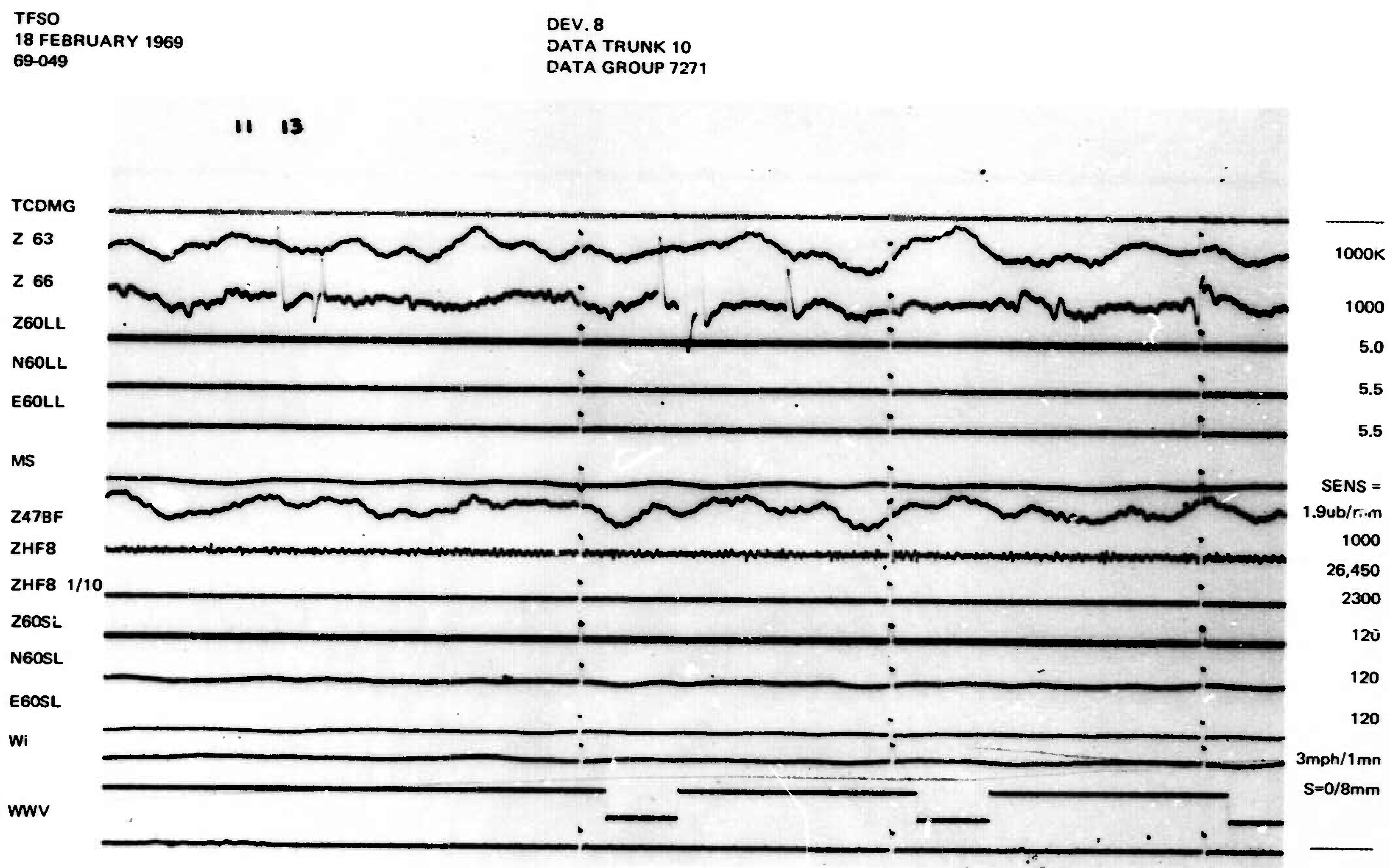


Figure 4. TFSO short-period seismograms exhibiting spikes on Z66, a solid-state system with data and power on the same pair. (X10 enlargement of 16-millimeter film)

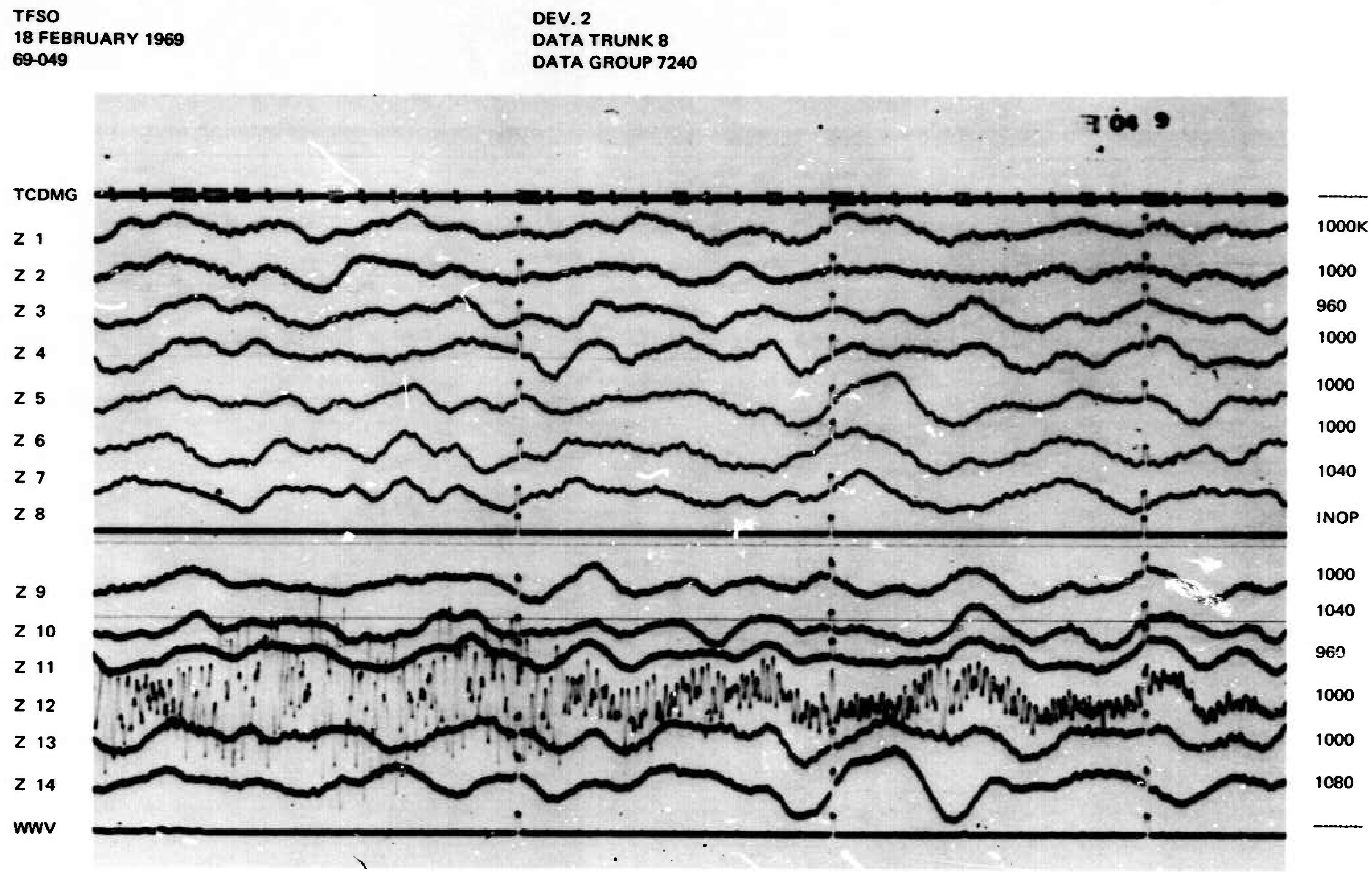


Figure 5. TFSO short-period seismograms of solid-state systems having power on one pair and calibrations and data on the other pair. Note the absence of spikes as compared to Z66 on DT 10 at same time interval. (Z12 noisy, cause unknown) (X10 enlargement of 16-millimeter film)

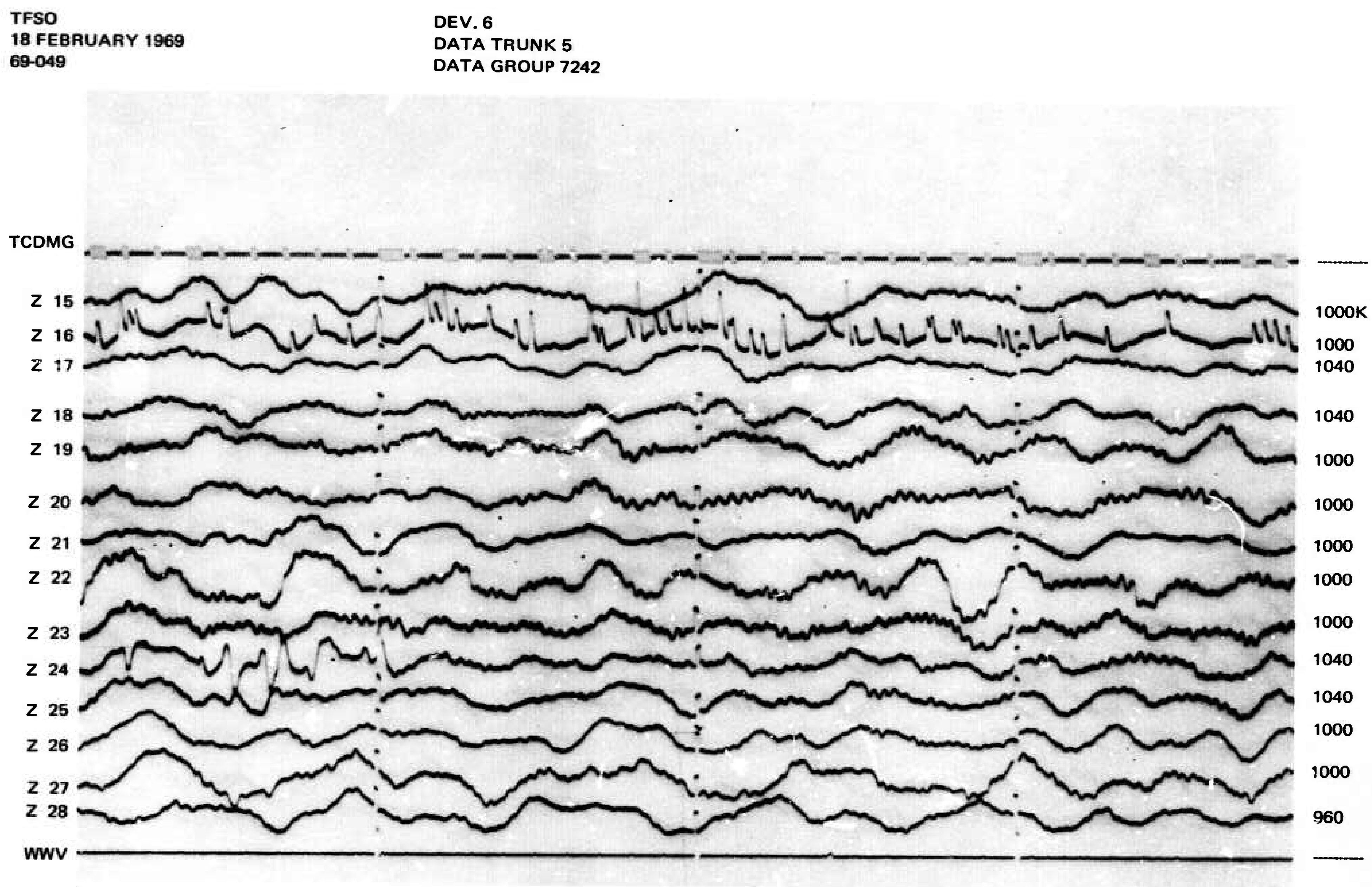


Figure 6. TFSO short-period seismograms of solid-state systems having power on one pair and data and calibration on other pair. Note the absence of spikes as compared to Z66 on DT 10 at same time interval. (Z16 noisy, cause unknown) (X10 enlargement of 16-millimeter film)

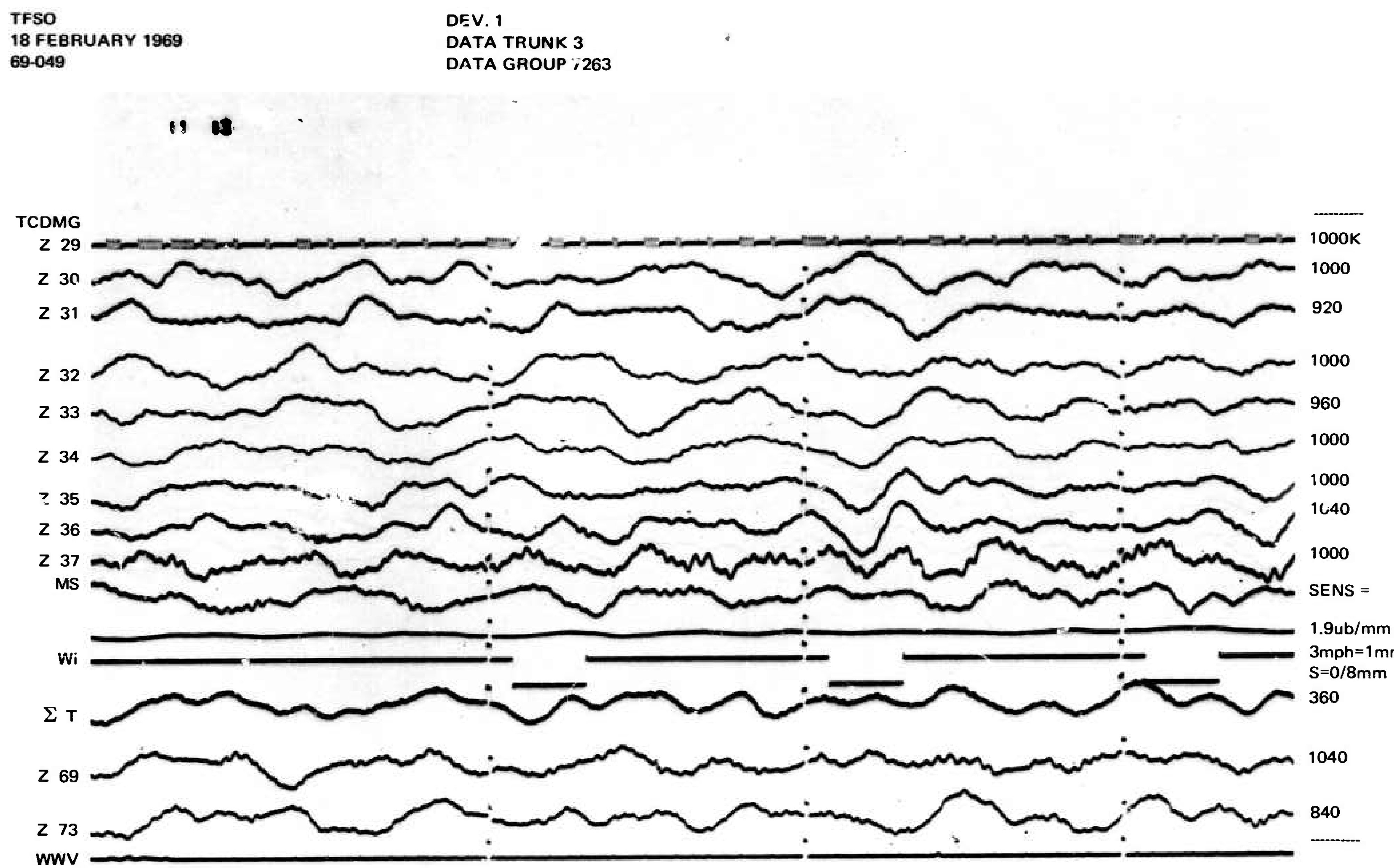


Figure 7. TFSO short-period seismograms of solid-state systems having power on one pair and calibration and data on other pair. Note the absence of spikes as compared to Z66 on DT 10 at same time interval. (X10 enlargement of 16-millimeter film)

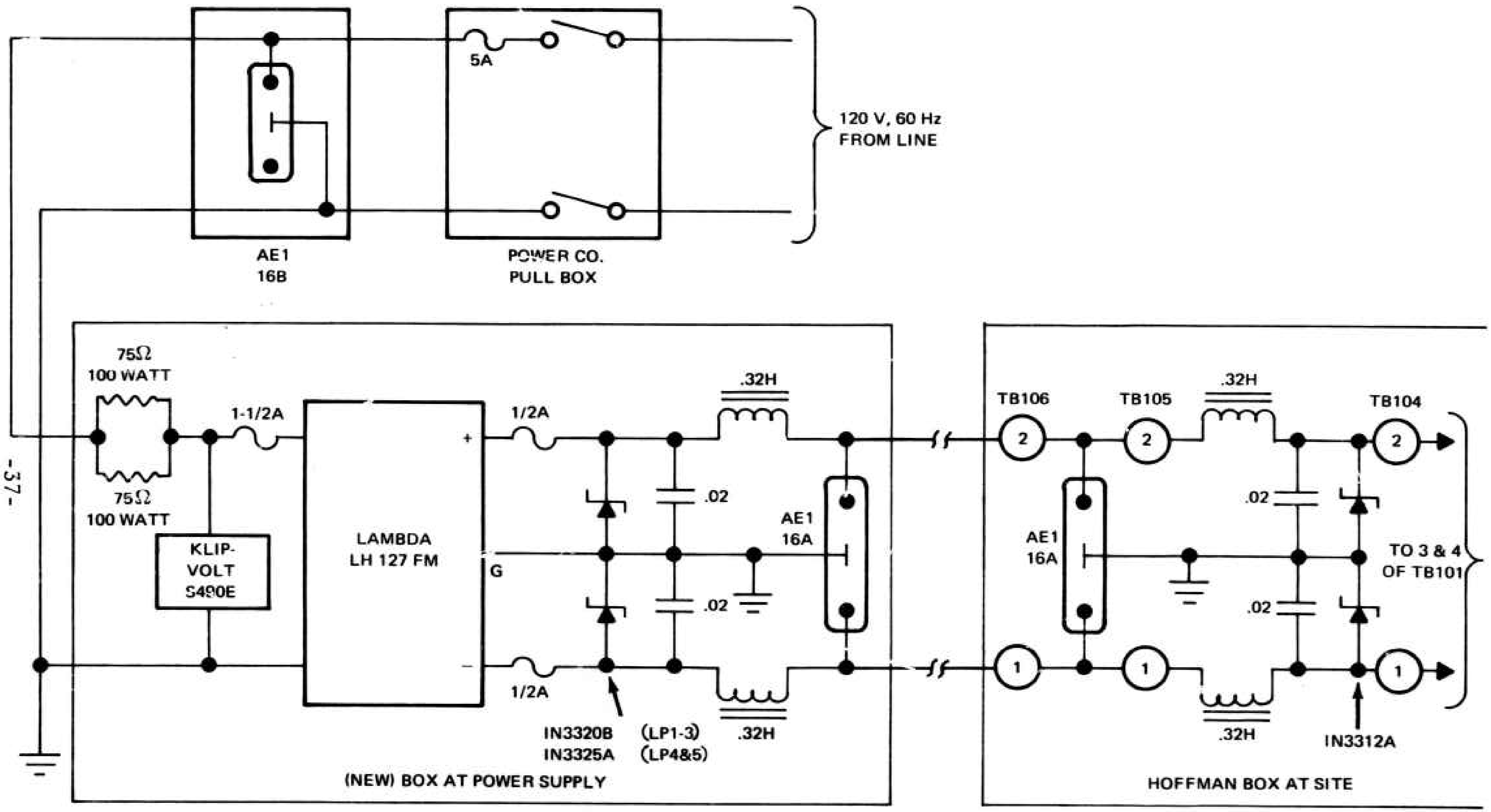


Figure 8. New lightning protection for LP power circuits at sites 1, 2, 3, 4 and 5

G 5049

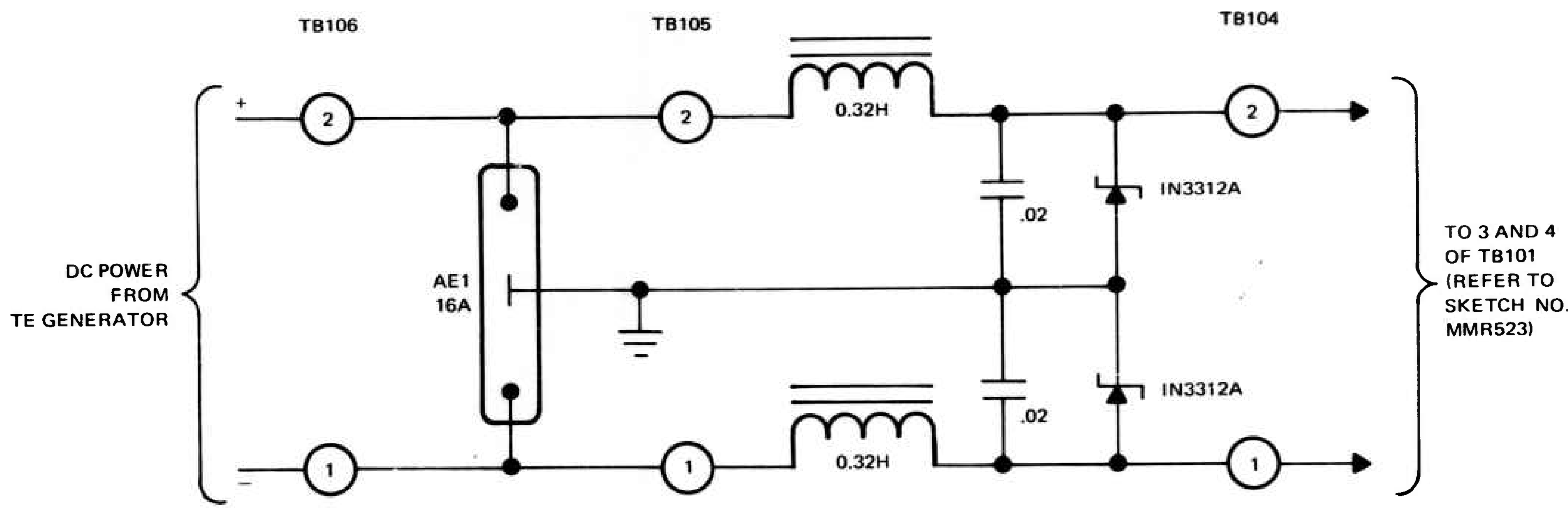


Figure 9. Lightning protection circuit for DC power to Hoffman boxes at TFSO sites LP6 and LP7

G 5050

Modification of solid-state amplifiers was started during August to improve lightning protection for the power converter, and involves the removal of a 0.1 mfd feedback capacitor from between the ±10-volt common and the transformer center tap on the "B" board of the power converter. All amplifiers are being modified as they come in from the field for repairs. To date, eight amplifiers have been modified.

4.2.2 Solid-State Amplifier

At the beginning of this report period, all long-period seismic amplifiers except those at LP1 were installed in tank vaults with seismometers. This required that a vault be opened whenever an amplifier required checking, adjustment, or maintenance. Such a procedure was undesirable, for it disturbed the seismometer, permitted moisture to enter the tank, and required considerable time and effort, as the tanks are buried under several feet of sawdust and earth. This undesirable situation was corrected by relocating the amplifiers in the Hoffman boxes at each site except LP1 and LP4, which are non-standard and do not use Hoffman boxes. The relocation was first tested at LP3 and found to cause no deterioration in seismograph performance, and then was accomplished at other sites. Figures 10 and 11 show the LP3 installation. An insulated wood box is used to cover the Hoffman box and stabilize its interior temperature.

4.2.3 Calibration Circuit Transients

During analysis of LP data recorded on digital magnetic tape, it was noted that frequently a large transient appeared at the beginning of each sinusoidal calibration and overloaded the Astrodata system. At times, the overload persisted throughout the calibration and made it valueless. The transient was traced to a small unbalance in the calibration discriminator output and a small shift in the VCO center frequency. Both deviations were within instrument operating specifications but were greatly magnified because the VCO and discriminator were being operated at a very small deviation during calibrations. The routine 12 μA p-p calibration current produced a frequency deviation of only 0.09 percent p-p. The frequency deviation of the calibration system was increased by a factor of 10, and the circuit at LP1 was modified and tested. When this was found to reduce calibration transients to acceptable values, calibration circuits at all LP sites were modified.

4.2.4 Tone-Controlled Calibration Circuit

Some of the noise in the long-period data has been traced to spurious operation of the calibration discriminators at the field sites. Normally, these discriminators will be disabled unless they receive a calibration carrier from the central recording building. However, it was found that they can be triggered momentarily into an operational state by transmission system noise. An auxiliary, tone-controlled circuit that completely disconnects the discriminator output from the seismometer calibration coil when no tone is received was built and was tested at LP4. The concept was proven sound, but the equipment used was easily damaged by lightning and required frequent maintenance. LP4 calibration circuits were restored to their original configuration in order to keep the site operational without excessive maintenance effort.

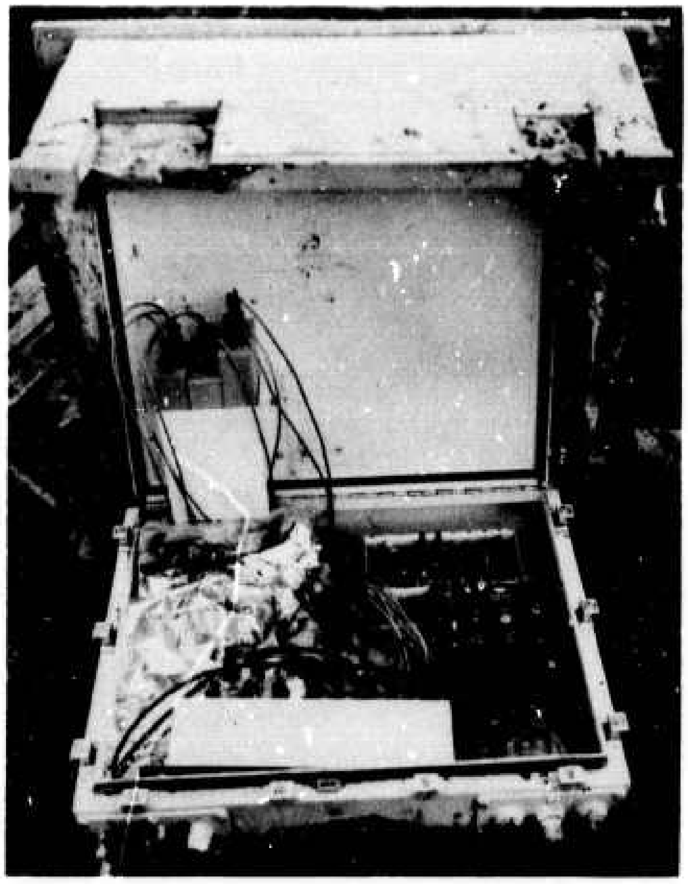


Figure 10. Amplifiers mounted in Hoffman box at LP3

Figure 11. View of Hoffman box at LP3 with insulated lid in place

G 4972

4.2.5 Horizontal Seismometer Case Seals

Plugs were removed from the cases of all long-period horizontal seismometers, and breather assemblies were installed after tests at LP1 and LP4 showed that this modification reduced seismograph noise. It is believed that this modification prevents mechanical distortion of seismometer bases due to pressure and temperature changes.

5. ROUTINE ANALYSIS

5.1 INTRODUCTION

Seismometric data were recorded at TFSO continuously throughout this reporting period. The recorded data were routinely analyzed, the analyses checked, and a daily tabulation of arrival times of P phases and selected later phases of earthquake signals were transmitted to the Environmental Science Services Administration's Coast and Geodetic Survey (ESSA-C&GS).

Sixteen-millimeter film seismograms and associated preliminary analysis data were routinely selected on a random basis by our Garland laboratory personnel for review by a quality-control analyst. Recorded data were also used to evaluate routine and special seismograph systems operated at TFSO and to obtain data for research studies.

5.2 ANALYSIS PROCEDURES

5.2.1 Preliminary Analysis

Film seismograms were analyzed during each 24-hour period. Preliminary analysis was conducted on an "on-line" basis and the analysis data were recorded on worksheets compatible to both observatory use and direct transcription of data to IBM cards. Data recorded during preliminary analysis consist of:

a. Phase arrival time;

b. Period and peak amplitude of each phase arrival;

c. Preliminary phase identification when possible;

d. Classification of events by general type (for example, local, near regional);

e. Estimated station-to-epicenter distance and/or azimuth (when possible);

f. Seismograph system and component.

5.2.2 Checking and Finalization of Preliminary Analysis

The seismograms were reviewed by a second analyst who checked the arrival time, period, and amplitude data recorded on the work sheets, and reviewed portions of the seismogram classified as "possible signal" by the preliminary analyst. Data from the analysis sheets were used for compilation of information for ESSA-C&GS.

5.2.3 Daily Reporting to the ESSA-C&GS

Throughout the reporting period, the arrival time, signal period, signal amplitude, and estimates of epicentral locations (when estimates were possible) of events recorded at TFSO were reported daily to the ESSA-C&GS in Washington, D.C. Daily messages, sent by TWX, were relayed to Washington, D.C., by the General Services Administration in Phoenix on week days, and were sent directly to Washington, D.C., on weekends and holidays. Data are used by the C&GS in their hypocenter location program.

Table 10 shows the number of events of each type reported by TFSO.

Table 10. Local (L), near regional (N), regional (R), and teleseismic (T) events reported to the C&GS by TFSO from 1 January through 31 December 1969

Month	L	N	R	T	Total
January 1969	5	140	10	640	795
February	2	482	15	644	1143
March	1	568	10	771	1350
April	1	135	17	846	999
May	1	111	7	781	900
June	0	76	17	1048	1141
July	2	83	16	996	1097
August	1	76	79	1706	1862
September	0	94	23	1381	1498
October	2	68	61	1148	1279
November	1	64	43	944	1052
December	5	80	17	1186	1288

6. INSTRUMENT EVALUATION

6.1 HIGH-FREQUENCY SEISMOGRAPH

The high-frequency seismograph, ZHF8, was operated routinely and was occasionally maintained from 1 January until 10 August, when lightning damaged the seismometer signal coils and substantially reduced the charges of some of the seismometer magnetic assemblies. By 29 October, the damaged signal coils were replaced, the magnets were recharged, resistor/diode lightning protector circuits were installed in the seismometer to protect the signal and calibration circuits, and the seismograph was returned to routine operation. During the remainder of the report period, the seismograph was operated routinely except for one time period during which isolation amplifier mainten ce was performed.

ZHF8 data were recorded continuously on the ASDAS magnetic tape with two exceptions: (1) They were not recorded during periods of maintenance; (2) They were not recorded from 24 September to 3 November 1969, when the ASDAS channel was used to record other data. Figure 12 shows the frequency response of the ZHF8 seismograph.

6.2 EXPERIMENTAL DEVELOCORDER PUMP, MODEL 30082

Testing was started during September 1968 to determine the long-time operational characteristics of the experimental Develocorder Pump, Model 30082, and was continued throughout the report period. The pump was operated routinely on Develocorder No. 9 under normal observatory operating conditions. The following observations have been made during these tests:

a. The hose failure rate (4 per year) on the new pump is approximately the same as the average failure rate on the 11 standard pumps operated during the same time period.

b. Rollers in the new pump seized and stopped turning soon after the pump was put into operation. This is not unusual - rollers in 5 of the 11 standard pumps have seized and stopped turning.

c. The new pump was easier to inspect than the old one.

d. Hose replacement on the new pump was easier and quicker (10 vs 60 minutes) than on the standard pump.

Operation of the experimental pump will be continued on a routine basis.

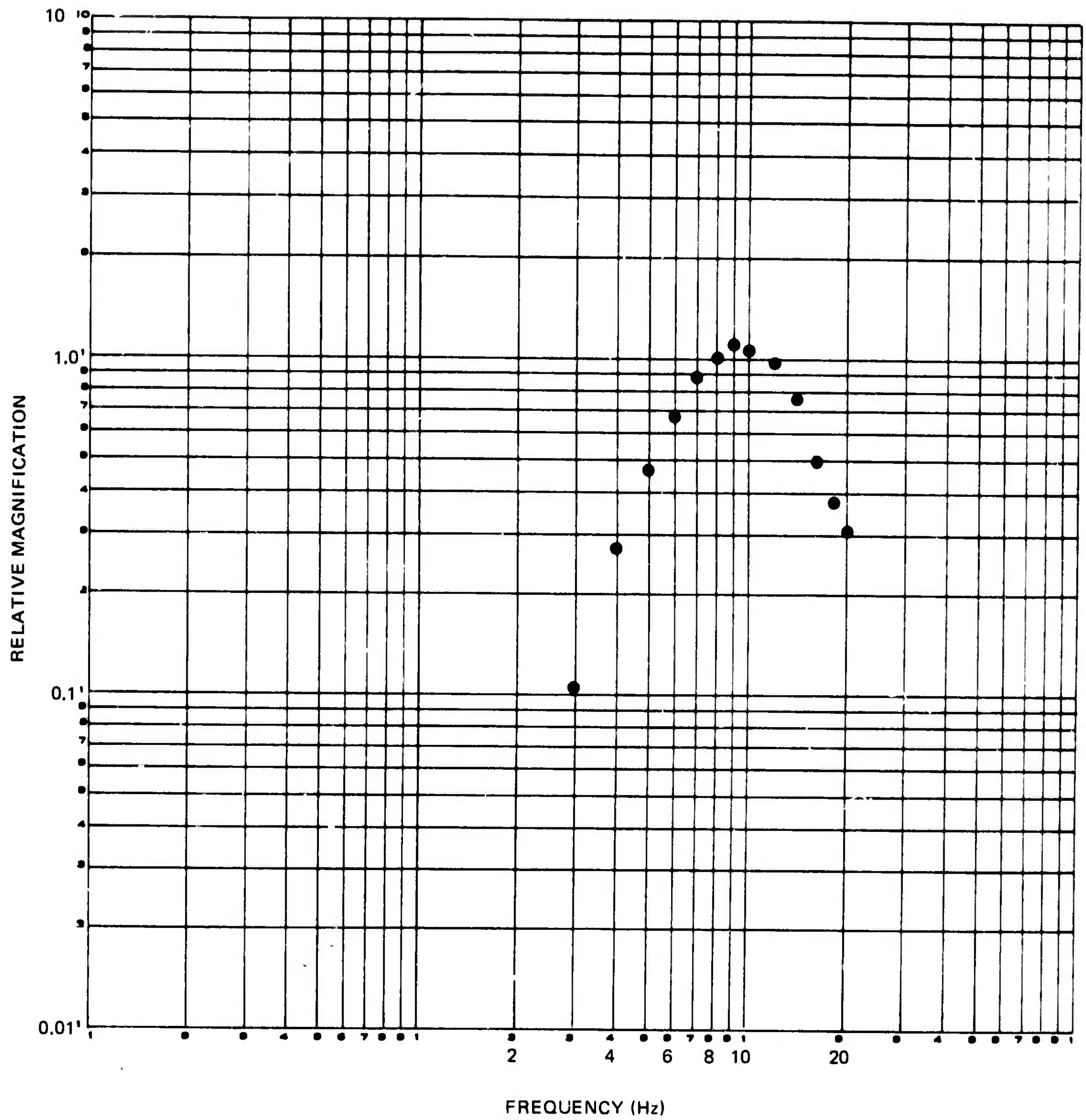


Figure 12. Frequency response of TFSO high frequency seismograph ZHF8

G 5487

6.3 MULTICHANNEL FILTER SYSTEM (MCF)

Comparison tests of the 19-point and 35-point filter programs, which were started on 22 December 1968, were terminated on 24 January. The MCF was made available to TI personnel until 27 January. On 27 January, a new format was established with five beam-steer traces using a new 35-point filter routine with different input instruments. The six omitted seismographs are Z6, Z9, Z12, Z15, Z24, and Z35. Prior to 24 January, the omitted seismographs were Z3, Z5, Z7, Z8, Z12, and Z16. The change in inputs was made to eliminate those traces that exhibit the highest level of cultural noise, which we attribute to vehicle traffic and construction of highway, pipeline, and subdivisions. Figure 13 shows a frequency response of the MCF output of beam steer No. 3, which includes the 35-point filter and the inputs as revised on 27 January. Figure 14 shows the response of this and other outputs. Table 11 lists the recording formats.

At the request of the Project Officer, changes in the auxiliary processor were begun 24 January so that a special format could be recorded for TI.

TI personnel installed additional circuits in the auxiliary processor and a program was put in MCF 1 and MCF 2. MCF 1 responds to low-frequency signals and MCF 2 responds to high-frequency signals. The output of the auxiliary processor is the difference between the squared values of these two MCF channels. The new output is designated MCFPR and responds to higher frequency energy with a positive deflection and to lower frequency energy with a negative deflection. Figures 15 and 16 show the responses of these outputs to signals of various frequencies.

On 7 February, the TI MCF programs were received and the Kurile Islands Program installed. Recording in this format has continued with the designations MCF 1, MCF 2, and MCFPR on Data Trunk 7, Data Group 7280. The recordings of this data trunk have been sent to TI on a weekly basis.

On 2 April 1969, the format was changed by deleting MCF 1, MCF 2, and MCFPR, and using a new trace, MCFLP, in place of MCF 1. MCFLP is a recording of LP data that has been routed through a modified channel of the MCF and recorded on Develocorder No. 5, Data Trunk No. 7. The MCF channel was modified to accommodate LP data without distortion. Two capacitors were removed to provide a flat frequency response from dc to 0.3 cps.

During July, noise that appeared intermittently at the beam-steered outputs was traced to temperature rise caused by dirt-clogged filters in the MCF forced-air cooling system. Cleaning the filters appears to have eliminated the noise. Later, lightning caused a fuse to fail in the ac regulator.

On 21 July, the MCF format was restored to its previous configuration. MCFLP was removed and MCF 1, MCF 2, and MCFPR were again made active channels.

Several attempts were made, during late November and throughout December, to set up the MCF auxiliary processor so that Fisher processing of data could be performed. The attempts were unsuccessful, as insufficient historical and instructional information about the MCF was available to permit establishment and testing of the required circuits.

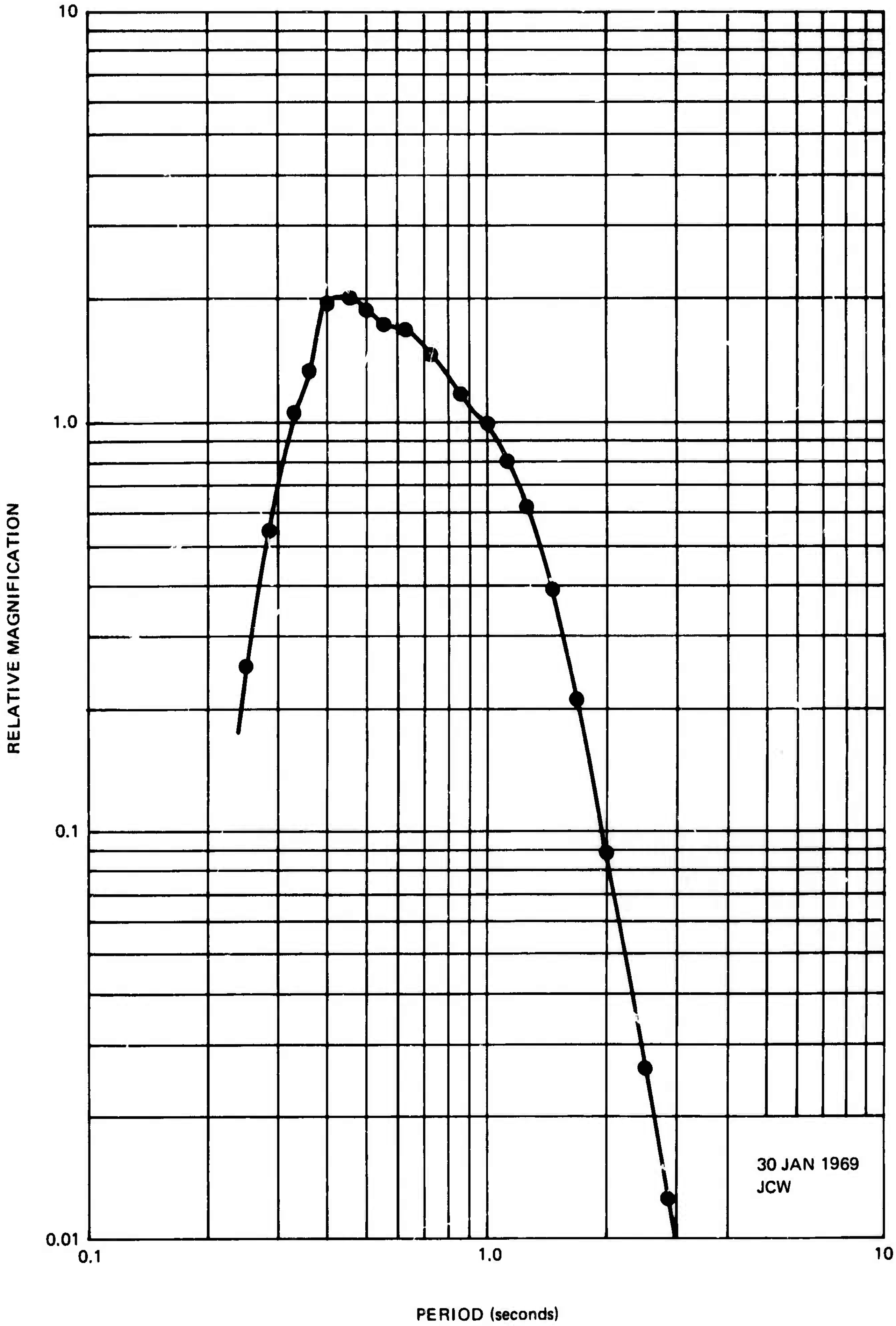


Figure 13. Frequency response for MCF using BS-3 (35 point) filter. This was used with data from TFSO channel Z4

G 4974

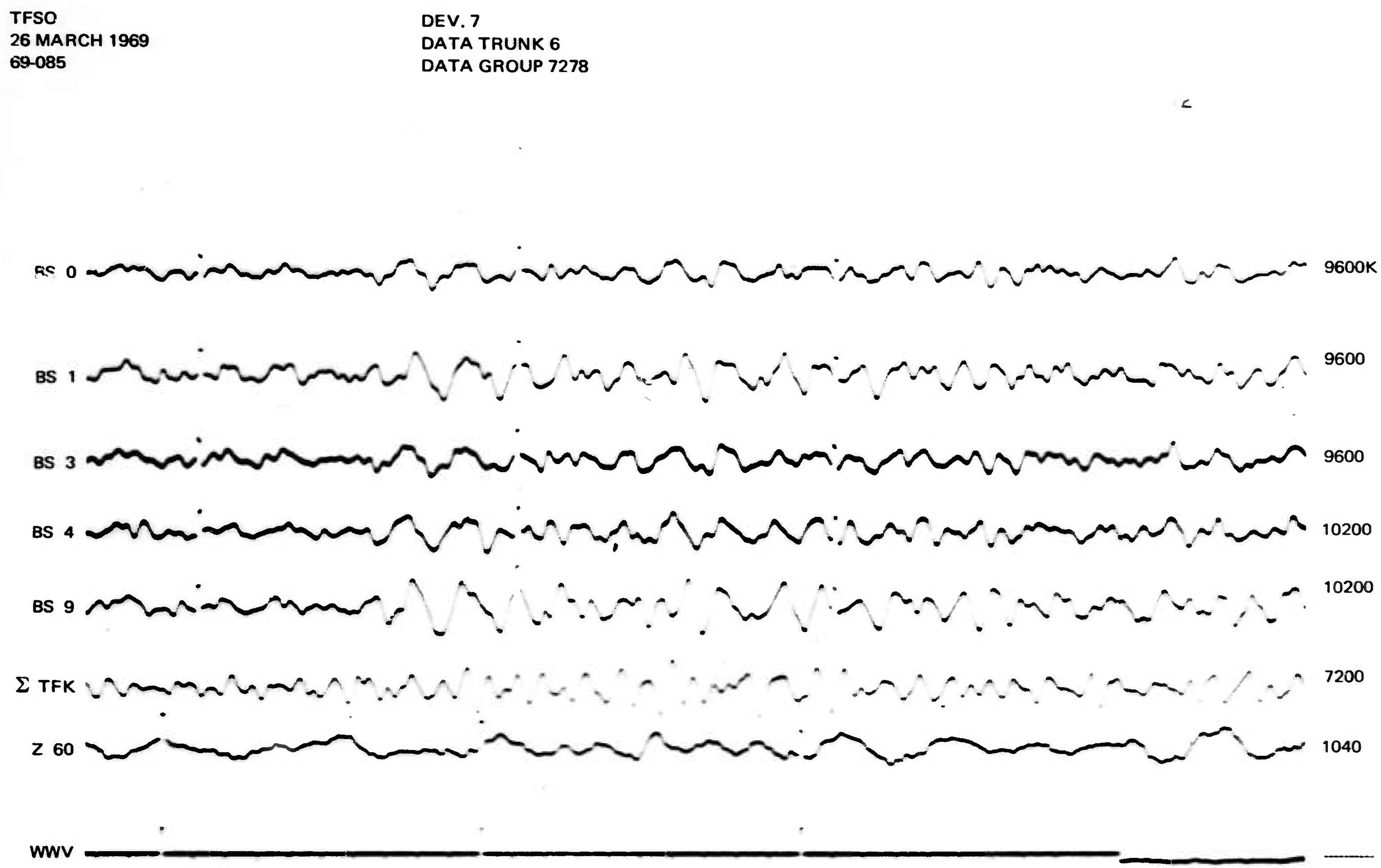


Figure 14. MCF seismograms exhibiting the response of BS traces to a low level teleseismic event, epicenter unknown. (X10 enlargement of 16-millimeter film)

Table 11. MCF recording formats from 1 January through 31 March 1969

Channel No.	Beam-steer output	Azimuth from TFSO	Distance from TFSO	Apparent velocity
	22 December 1968 through 24 January 1969			
1	BSO - 19 pt	353.8	97.0	24.2 km/sec
2	BSO - 35 pt	353.8	97.0	24.2
3	BS2 - 19 pt	315.9	64.7	17.1
4	BS2 - 35 pt	315.9	64.7	17.1
5	BS1 - 35 pt	313.2	69.7	17.8
6	BS3 - 35 pt	345.6	104.2	25.8
7	ΣTF			
8	Z60			
9	WWV			
	28 January through 31 March 1969			
1	BS 0	353.8	97.0	24.2 km/sec
2	BS 1	313.2	69.7	17.8
3	BS 3	345.6	104.2	25.8
4	BS 4	4.2	72.0	18.5
5	BS 9	311.1	51.0	14.5
6	ΣTFK			
7	Z60			
8	WWV			

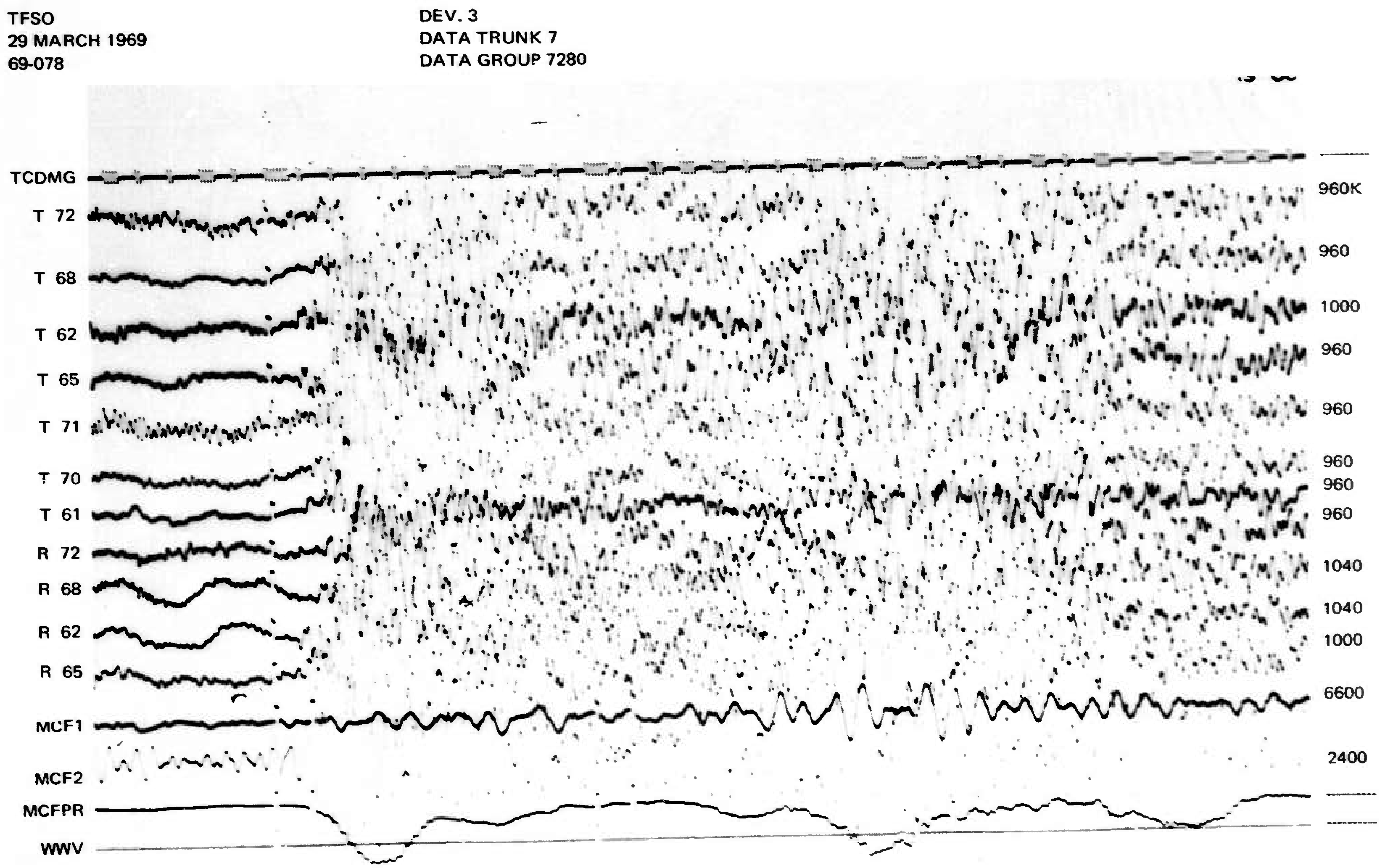


Figure 15. TFSO short-period seismograms exhibiting response of MCF1, MCF2, and MCFPR to a high frequency signal of a near regional event, epicenter unknown. (X10 enlargement of 16-millimeter film)

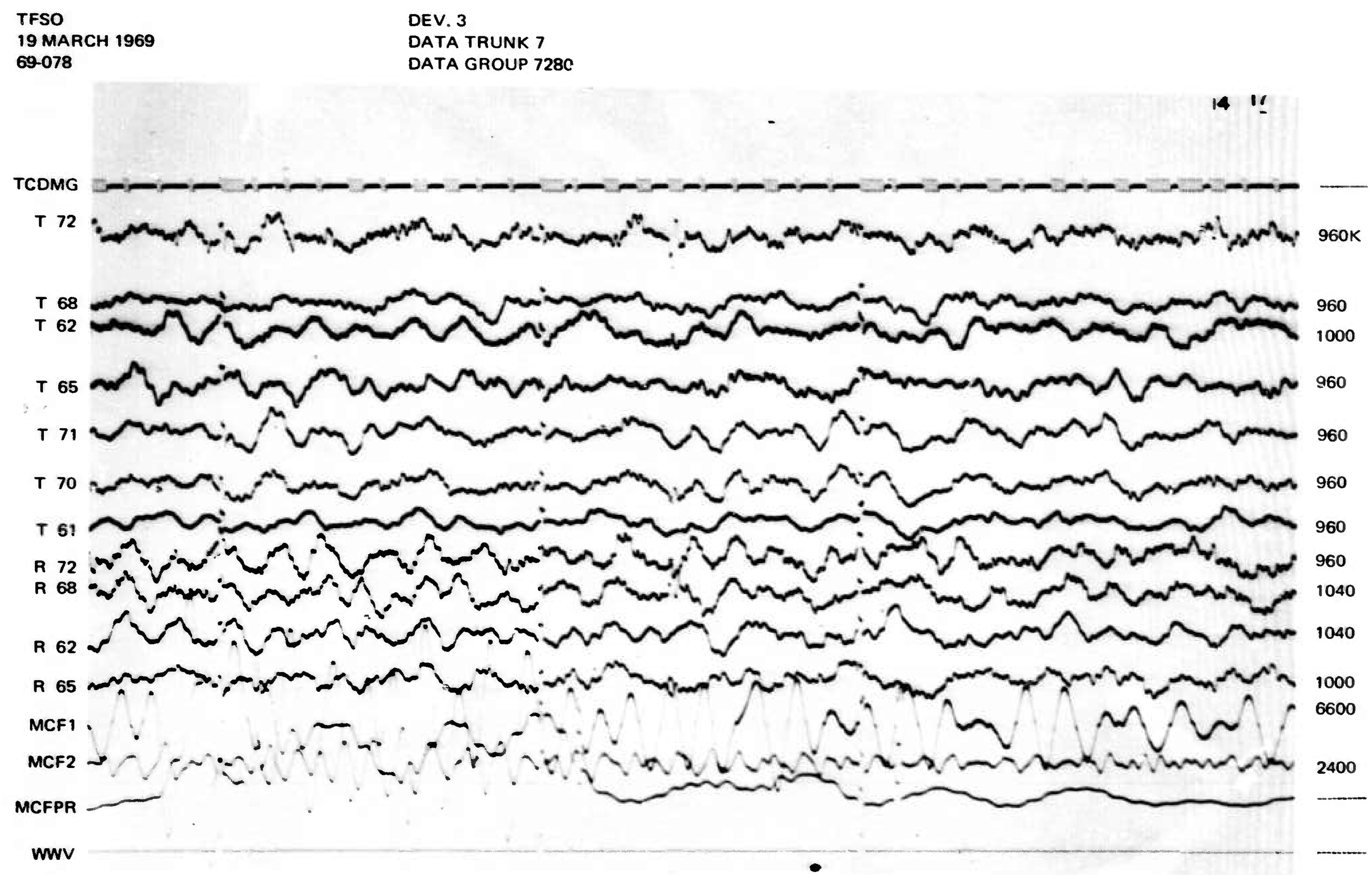


Figure 16. TFSO short-period seismograms exhibiting response of MCF1, MCF2, and MCFPR to low frequency signal of a teleseismic event, epicenter unknown. (X10 enlargement of 16-millimeter film)

6.4 EXTENDED LONG-PERIOD SEISMOGRAPHS

Work was started late in July to set up and operate two high-magnification, vertical, long-period seismographs at TFSO. These were designated ZXLP and ZYLP, and used 25-second seismometers, 115-second Harris galvanometers and phototube amplifiers. Their frequency responses, shown in figures 17 and 18, were closely matched and peaked at 40 seconds. Seismograms have been made on 16-millimeter film, analog FM tape, Helicorder paper, and digital tape, and have been sent routinely to SDL with other data shipments. Magnifications on film and paper were originally set to approximately 200K to permit viewing of small magnitude events but have been reduced to approximately 130K so that magnification at 25 seconds would equal that on Z1LP.

The seismometers and phototube amplifiers used with ZXLP and ZYLP were installed on the pier next to LP1 in the east underground vault.

Typical seismograms showing data ZXLP, ZYLP and other channels are included in this report. Figure 19 shows background noise recorded during a seismically quiet period. Figures 20 and 21 show phases received from small events.

6.5 EVACUATED LP HORIZONTAL SEISMOGRAPHS

The following tests were conducted using materials and equipment on hand to determine if there were immediately apparent advantages to operating LP horizontal seismometers in a partial vacuum.

6.5.1 Evacuated Seismometer

A horizontal LP seismograph, designated EXLP, was installed in the east walk-in vault during April 1969. It used a seismometer, Geotech Model 8700C, installed next to the LP1 seismometers, and signal transmission and conditioning equipment that made its magnification and frequency response equivalent to the standard LP array seismograph channel. The seismometer was oriented in an east-west direction, and all joints in its case were sealed with RTV silicone rubber or DC-4 silicone grease until a leak time constant of approximately 4400 hours was realized. The seismograph was operated routinely for 15 days with the case evacuated to 2 mm of mercury and was operated for 6 days with the case unsealed. Seismograms for these time periods showed very close agreement between EXLP traces and E1LP traces except for infrequent, intermittent, large-amplitude spikes that appeared on the EXLP trace during its operation with an evacuated case.

6.5.2 Evacuated Tank Vault

While operational tests were being conducted using a seismometer with an evacuated case, work was undertaken to seal the experimental surface tank vault that is located approximately 1/4 mile from both the CRB and LP1 vault. By replacing the cable entry condulet with a hermetically sealed header, pouring a new, low-porosity concrete floor, painting both the interior and exterior of the tank with epoxy, and pouring a new RTV-30 gasket in the tank lid, the time constant of the tank was raised from less than 8 hours to

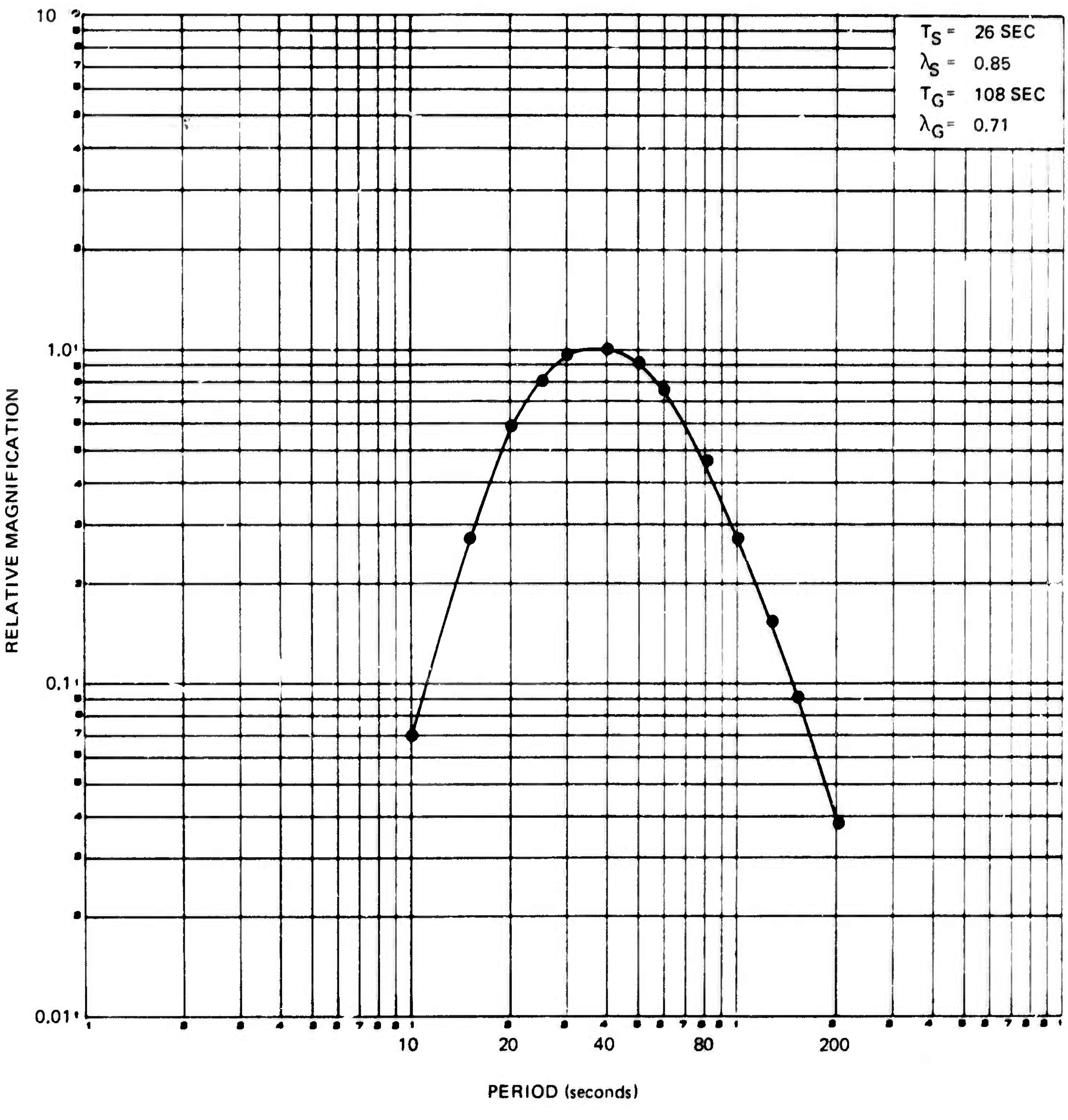


Figure 17. Frequency response of TFSO experimental long period seismograph ZXLP

G 5488

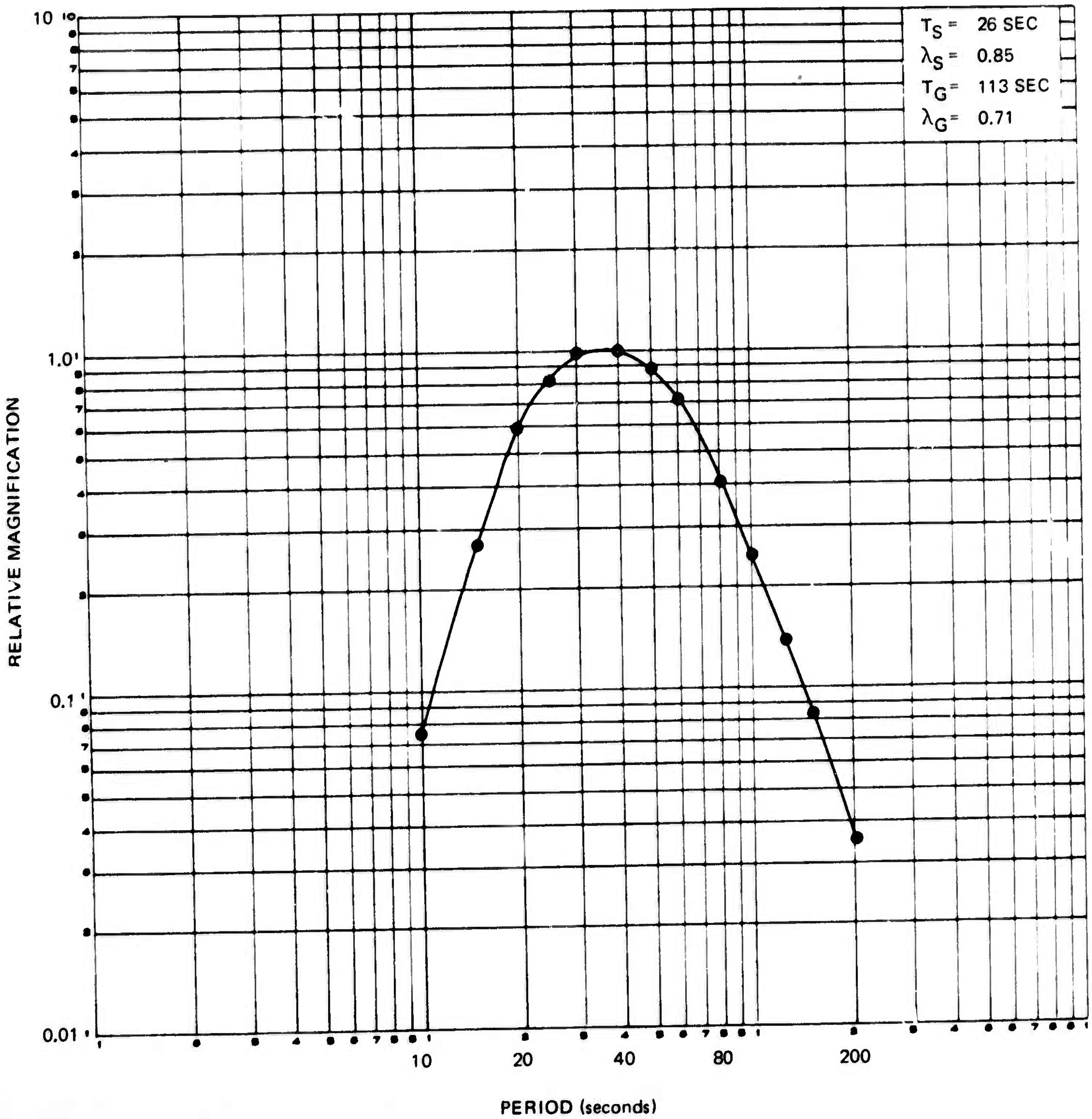


Figure 18. Frequency response of TFSO experimental long-period seismograph ZYLP

G 5489

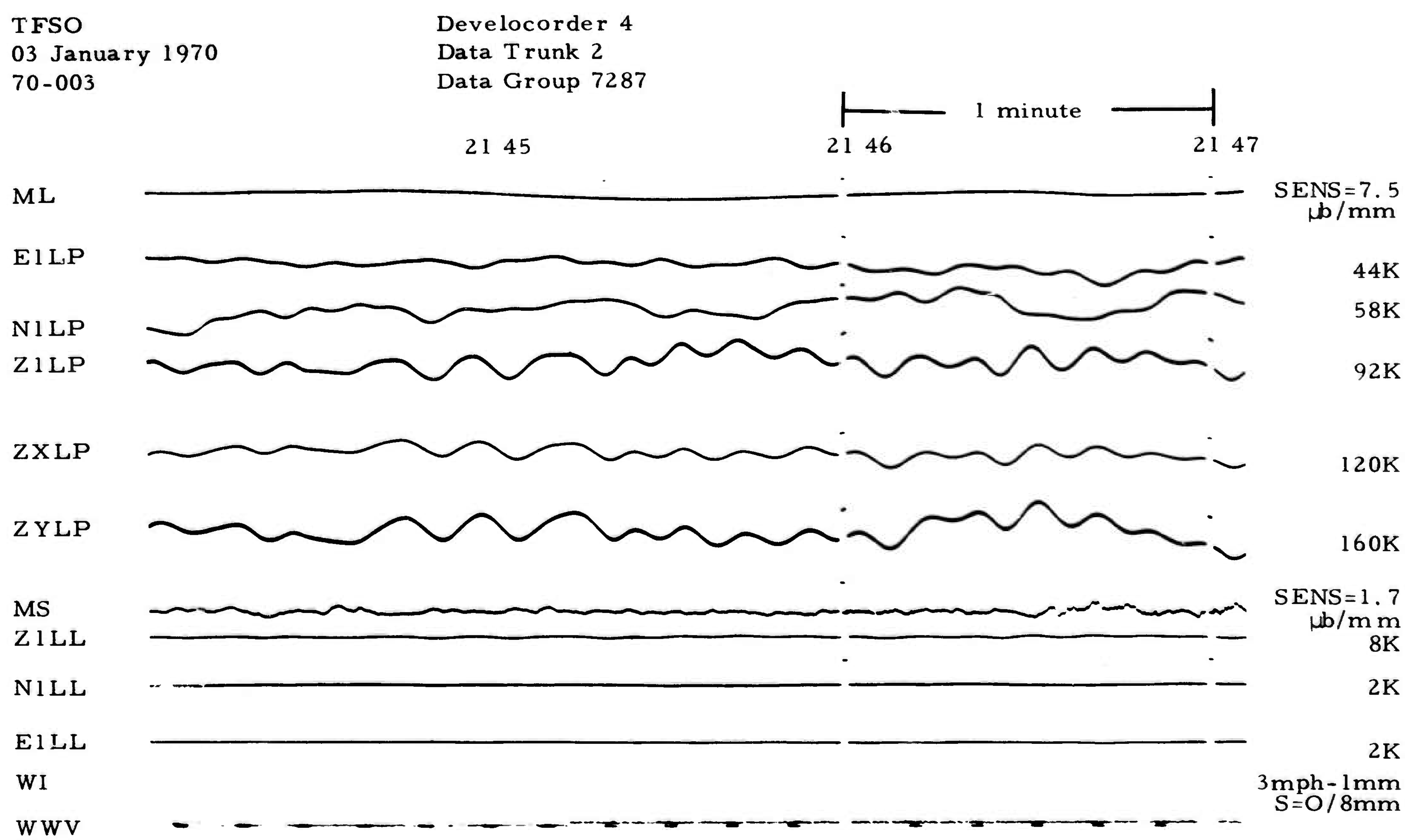


Figure 19. Long-period seismogram showing responses of ZXLP, ZYLP, and Z1LP to typical seismic background noise during a quiet period

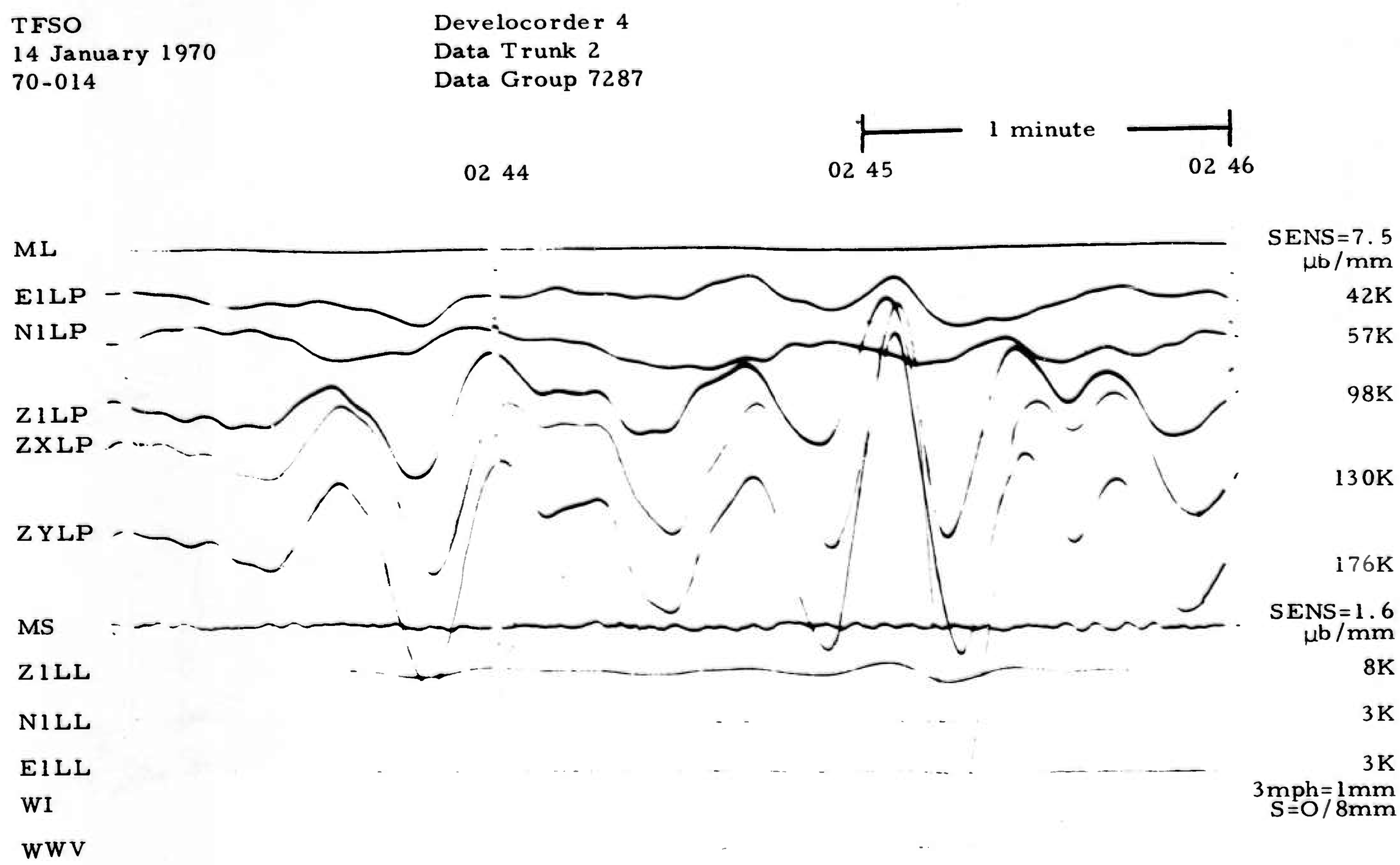


Figure 20. Long-period seismogram showing responses of ZXLP, ZYLP, and Z1LP seismographs to the PP phase of an event having an epicenter located approximately 130 degrees WSW of TFSO

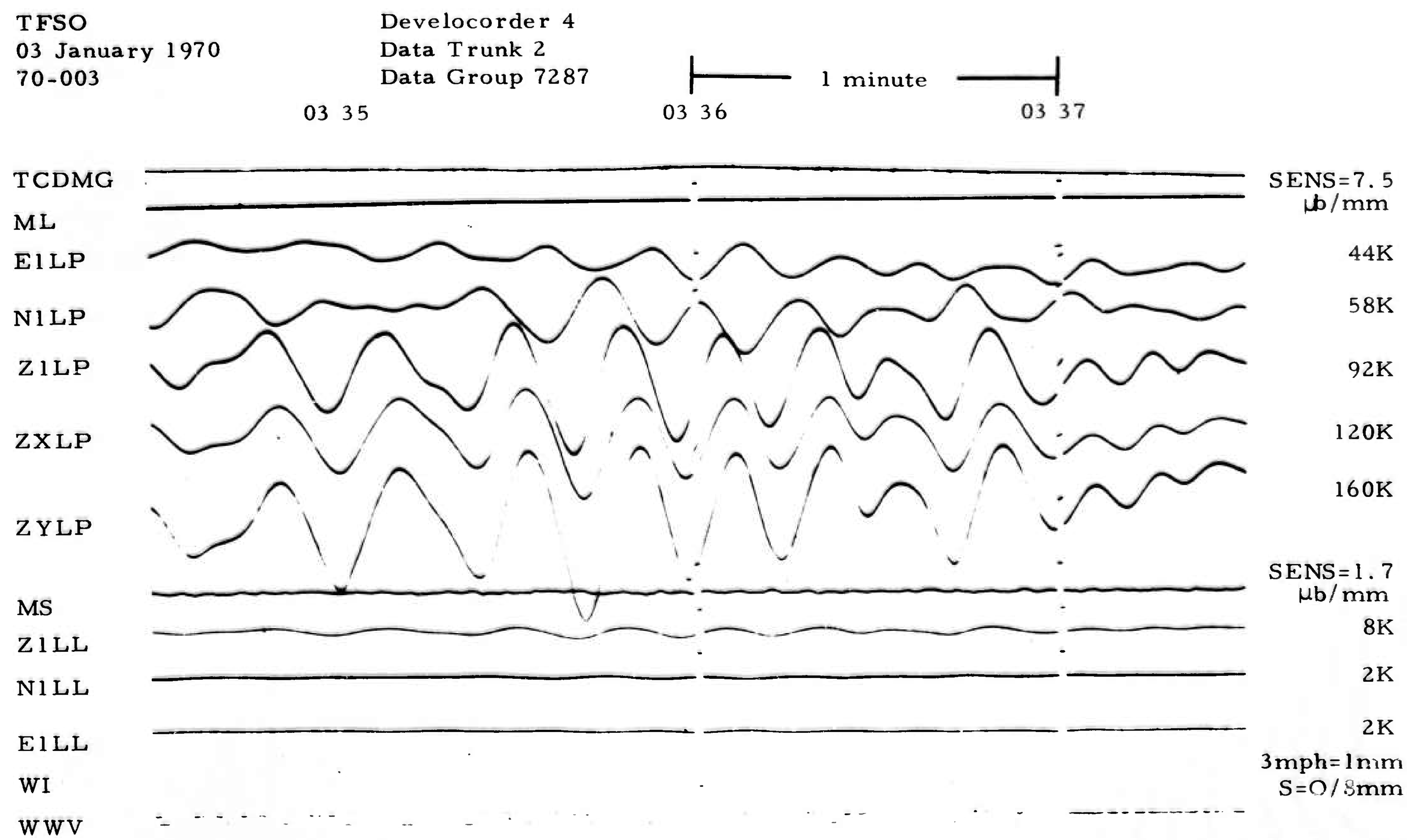


Figure 21. Long-period seismogram showing response of ZXLP, ZYLP, and Z1LP to Rayleigh waves from an event of unknown epicenter

approximately 1200 hours. The EXLP seismometer was removed from the underground vault and was installed in the newly sealed experimental tank vault. Its amplifier was installed nearby in an insulated box, and this seismograph, still designated EXLP, was adjusted to have the standard LP array magnification and frequency response. The seismograph was operated routinely for several weeks with the tank vault evacuated to 1 mm of Hg. Seismograms for this time period showed very close agreement between EXLP and E1LP during quiet periods and a greater increase in noise on the EXLP trace than on the E1LP trace when winds were blowing. Figures 22 through 28 show typical seismograms from these tests.

Additional recordings were made under the following conditions of operation:

a. With the tank vault sealed but not evacuated;

b. With the vacuum pump operating and a motor generator set running near the tank vault;

c. With the vacuum pump operating and a motor generator set running 200 feet from the tank vault.

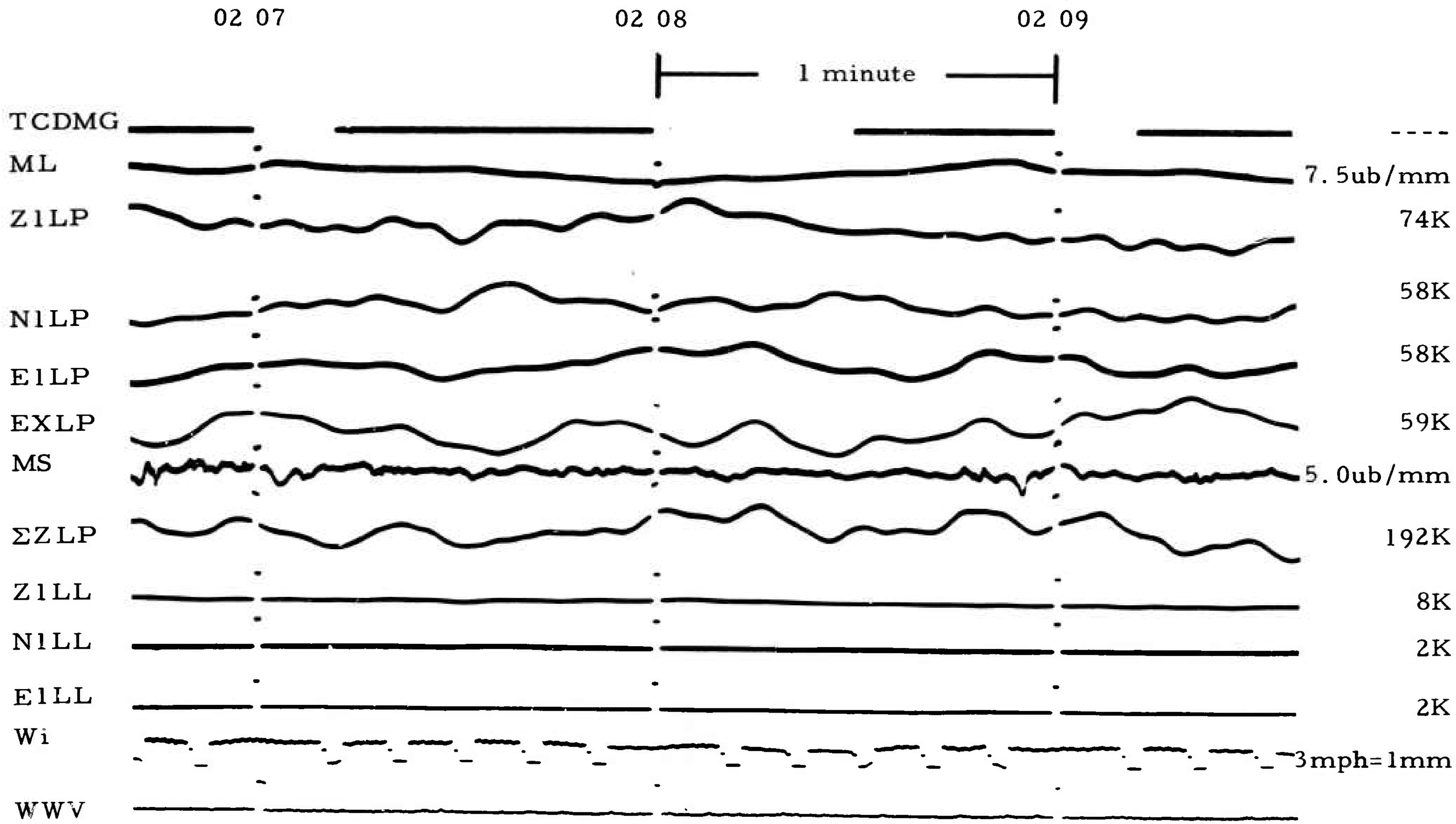
The test results were inconclusive. Although all data showed that noise was introduced when the motor generator set operated near the tank vault and was lessened when it was moved 200 feet from the vault, only some data showed that stopping the vacuum pump reduced the recorded LP noise. Other data showed that operating the vacuum pump apparently introduced no noise.

6.5.3 Discussion of Results

The test results indicate there is no advantage to operating a horizontal LP seismometer in a partial (1-2 mm of Hg) vacuum, and furthermore, showed that neither the seismometer case nor the tank vault are suitable for evacuated operation. Neither was designed for such service, and lacks the mechanical strength and the seals required. It is recommended that further tests of evacuated seismographs be conducted using equipment designed specifically for that purpose.

6.6 NITROGEN-FILLED LP TANK VAULTS

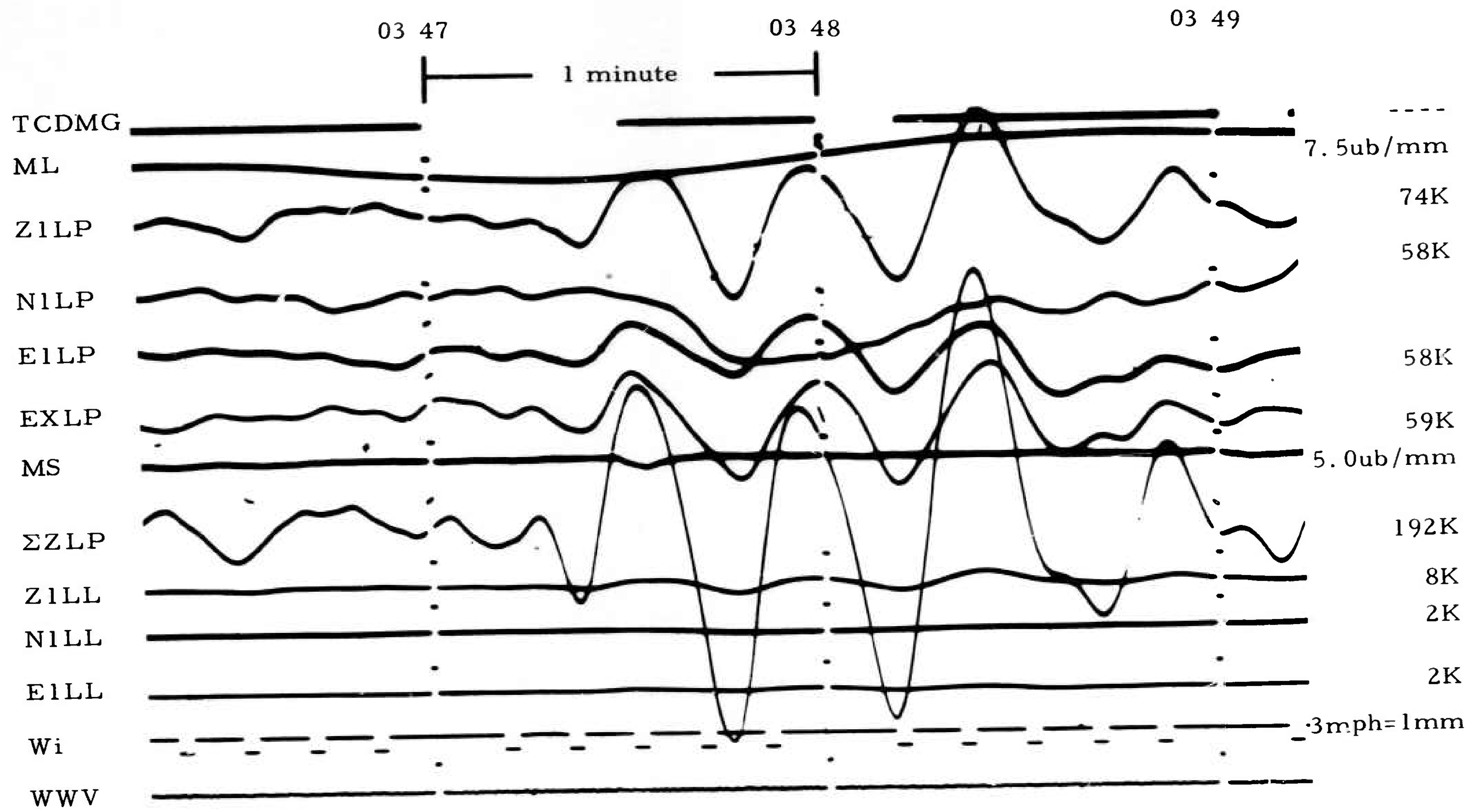
On 22 November, equipment was installed at LP7 to determine the performance improvements that will be derived and the problems that will be encountered from operating LP seismometers in tank vaults pressurized with 1 psi dry nitrogen. It is believed that pressurizing the tanks with dry nitrogen will exclude moisture and will prevent the condensation which now causes electrical leakage paths and increases the system noise. A standard commercial nitrogen tank, a pressure regulator, three gauges and three shutoff valves were interconnected and installed in a lockable wooden box, as shown in figure 29, and the entire assembly was transported to LP7. Each tank vault was connected to the nitrogen tank through a separate cutoff valve and a separate low-pressure line. Tank vault pressure was measured by one gauge, nitrogen tank pressure by the second, and nitrogen tank contents by the third. Upon completing the



TFSO
24 June 1969
69-175

Dev. 4
Data Trunk 2
Data Group 7284

Figure 22. Long-period seismogram showing responses of EXLP and E1LP to typical night background when operating at normal magnifications. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)



TFSO
24 June 1969
69-175

Dev. 4
Data Trunk 2
Data Group 7284

Figure 23. Long-period seismogram showing responses of EXLP and E1LP to a group of surface waves. Epicenter is unknown. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)

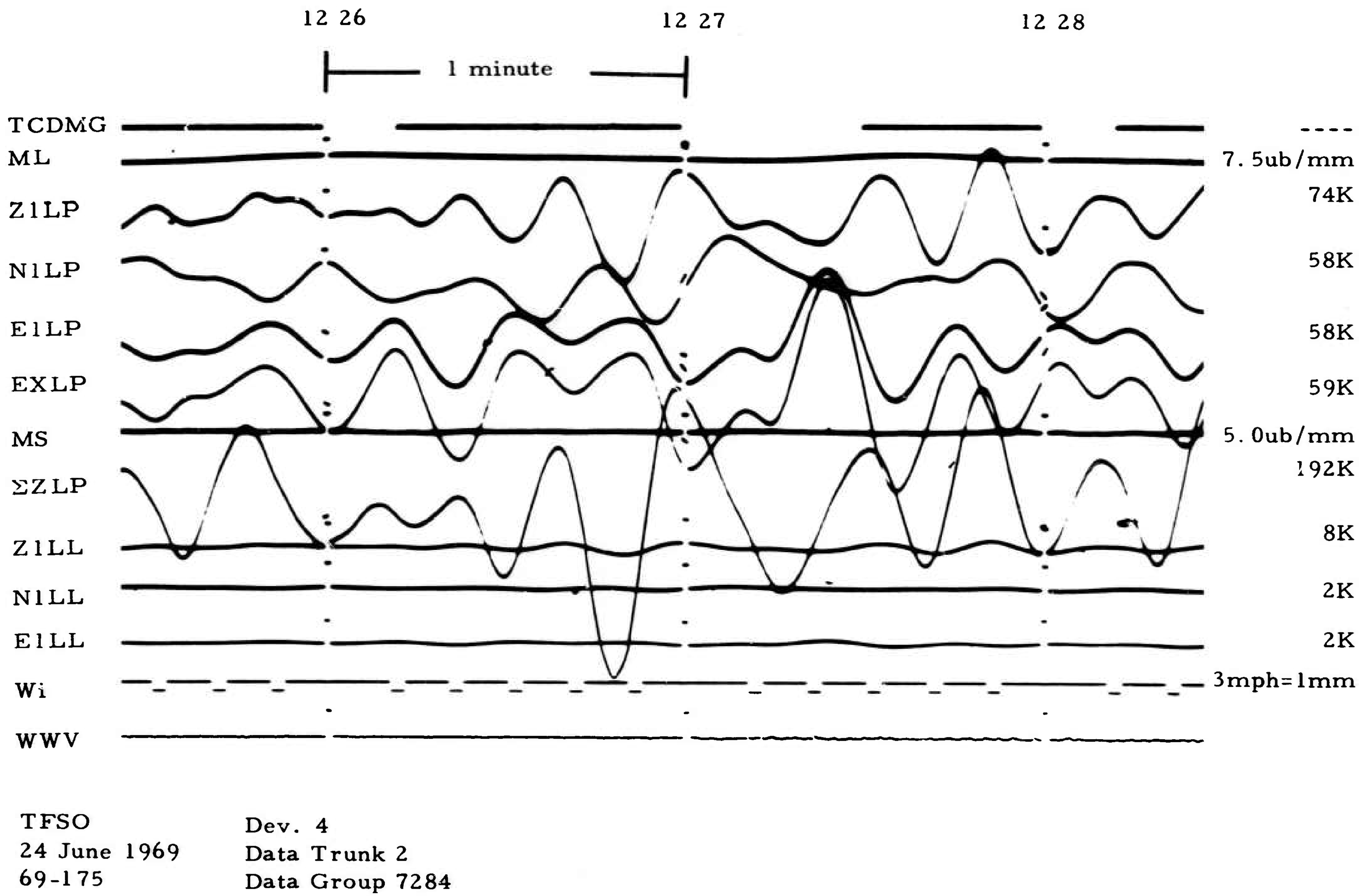
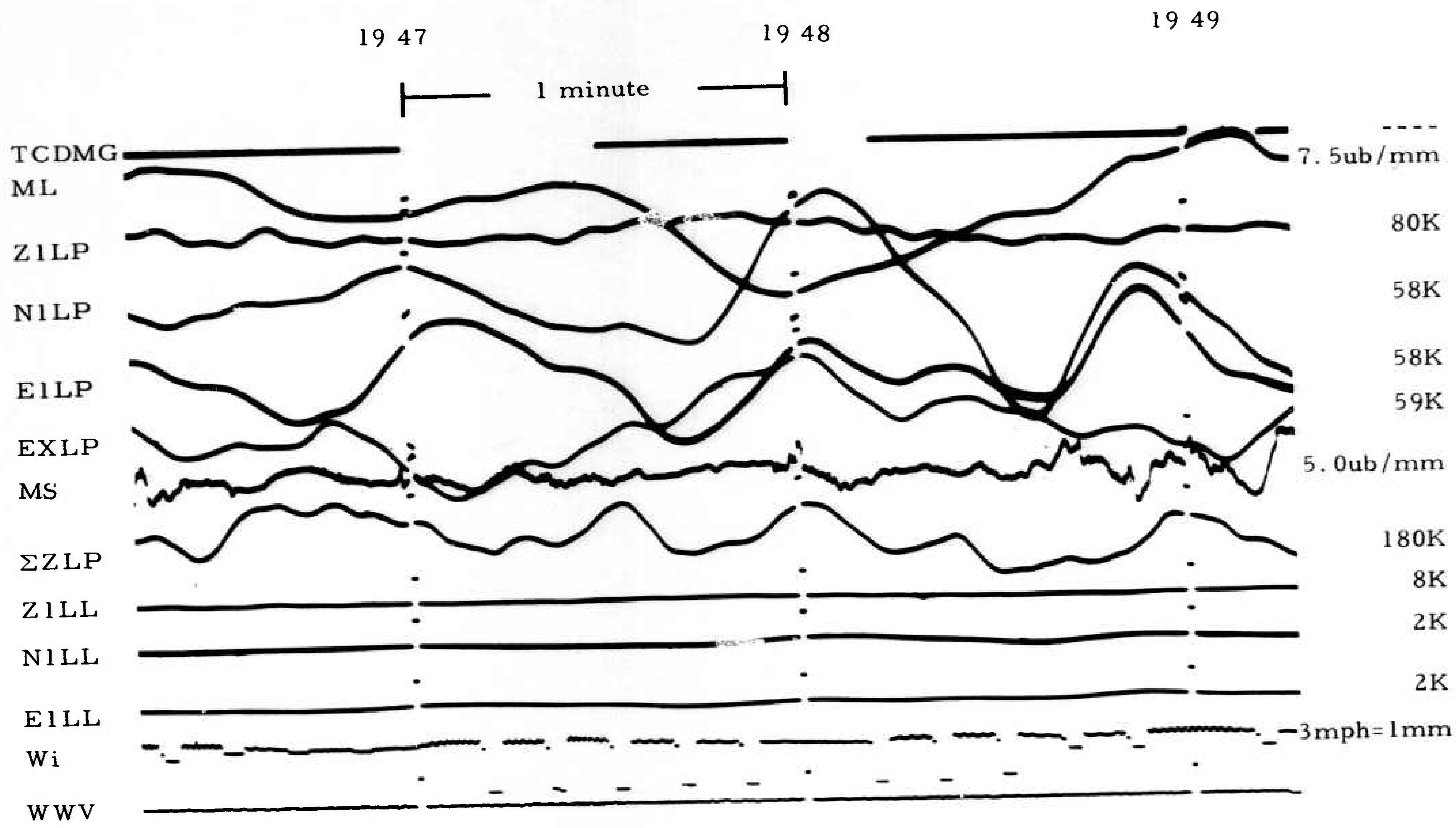


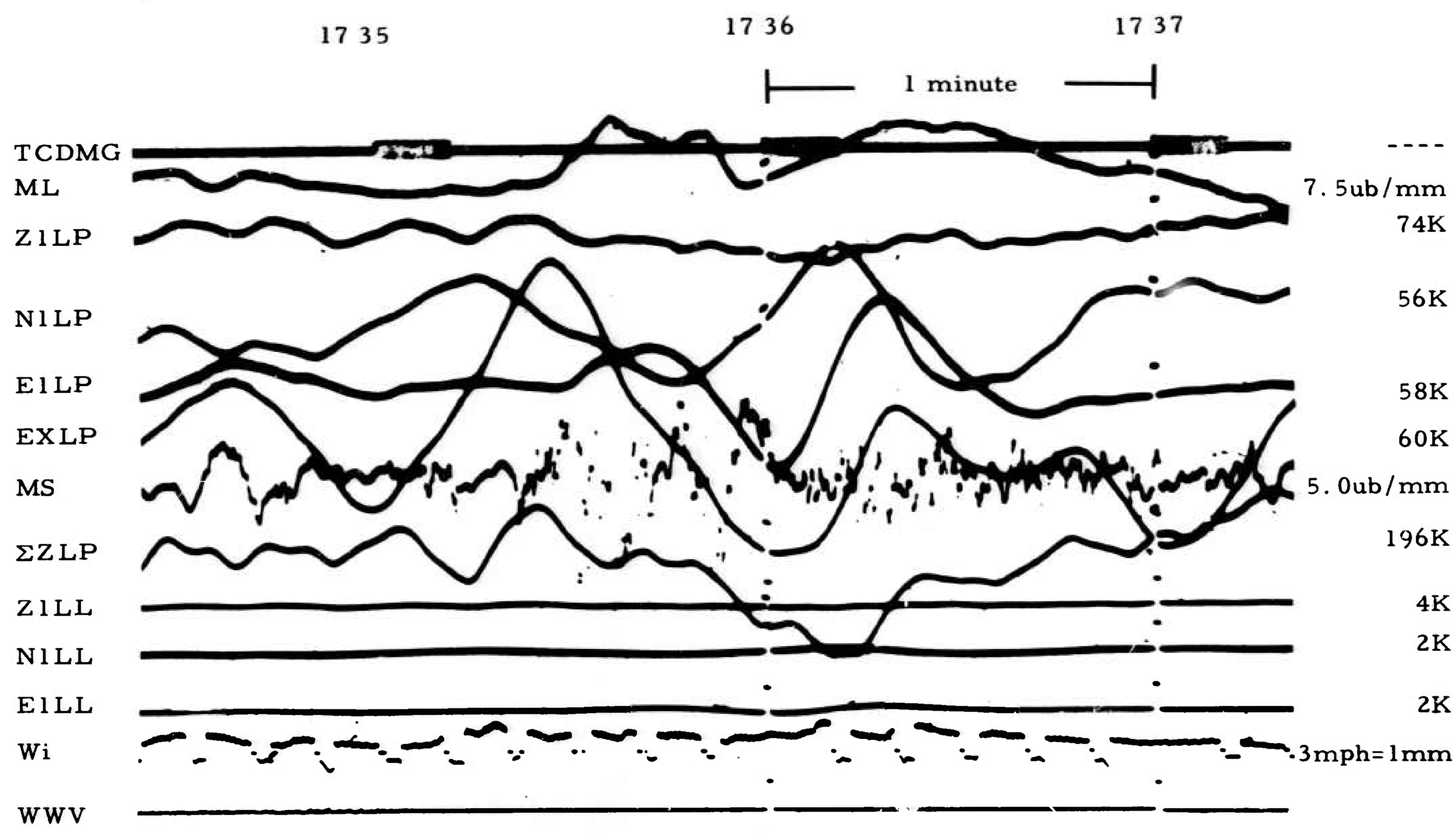
Figure 24. Long-period seismogram showing responses of EXLP and E1LP to a group of surface waves. Epicenter is unknown. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)



TFSO
23 June 1969
69-174

Dev. 4
Data Trunk 2
Data Group 7284

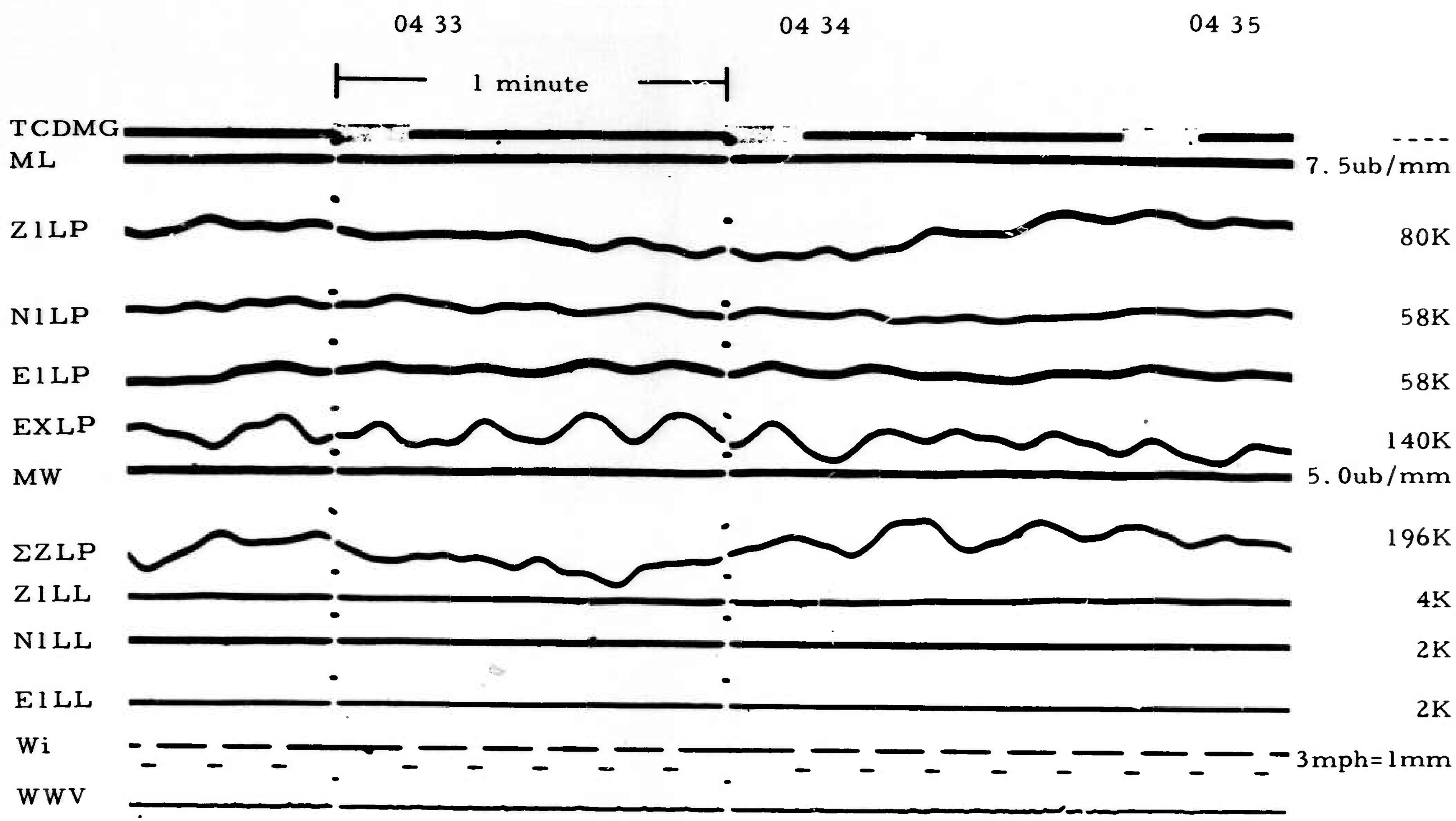
Figure 25. Long-period seismogram showing responses of EXLP and E1LP to atmospheric pressure changes. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)



TFSO
24 June 1969
69-175

Dev. 4
Data Trunk 2
Data Group 7284

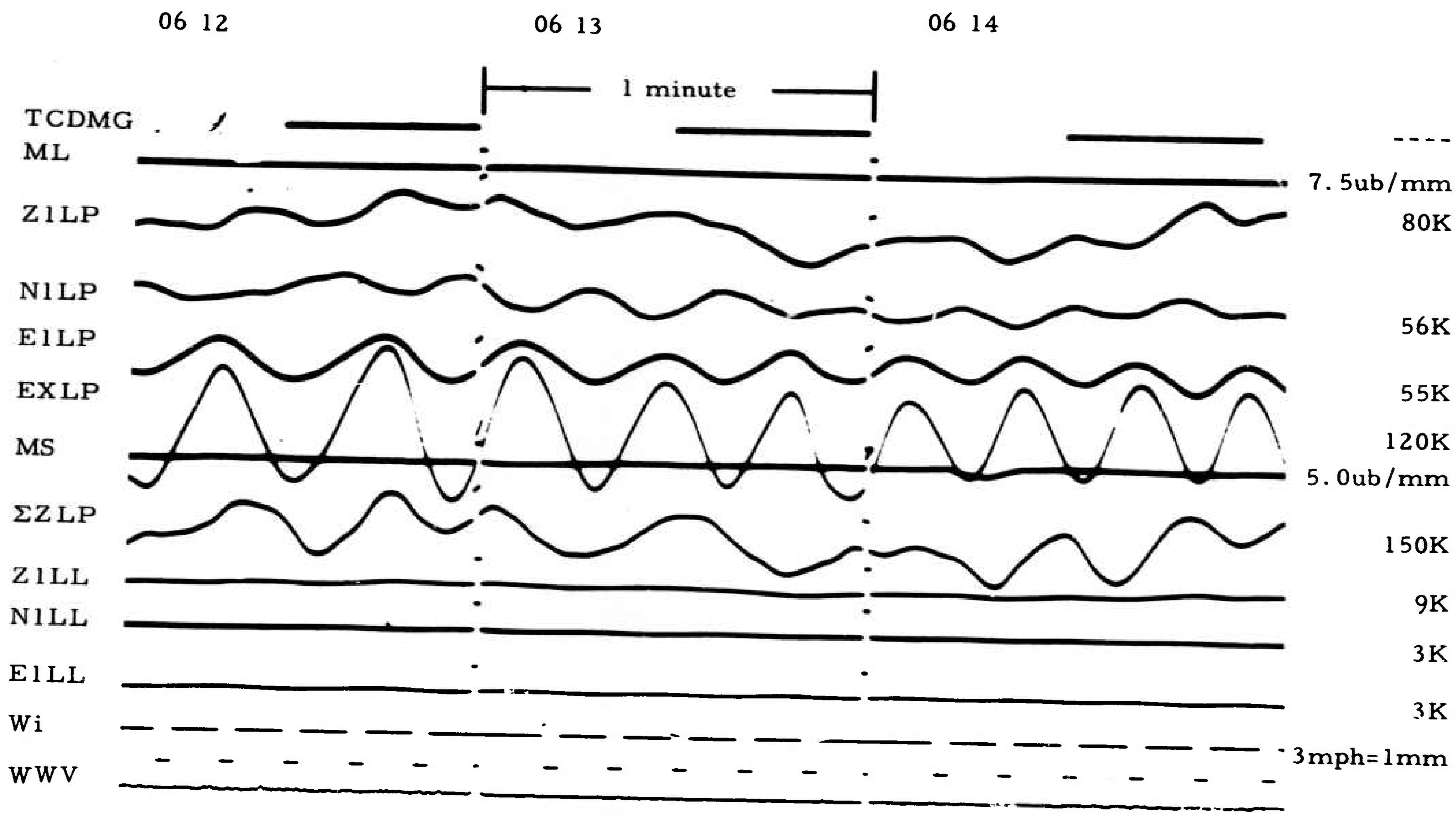
Figure 26. Long-period seismogram showing responses of EXLP and E1LP to wind. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)



TFSO 21 June 1969 69-172

Dev. 4 Data Trunk 2 Data Group 7284

Figure 27. Long-period seismogram showing response of EXLP and E1LP to typical night background with EXLP operating at 140K magnification. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)



TFSO
21 June 1969
69-172

Dev. 4
Data Trunk 2
Data Group 7284

Figure 28. Long-period seismogram showing response of EXLP and E1LP to surface wave train. Epicenter is unknown. EXLP vault was evacuated. (X10 enlargement of 16-millimeter film)

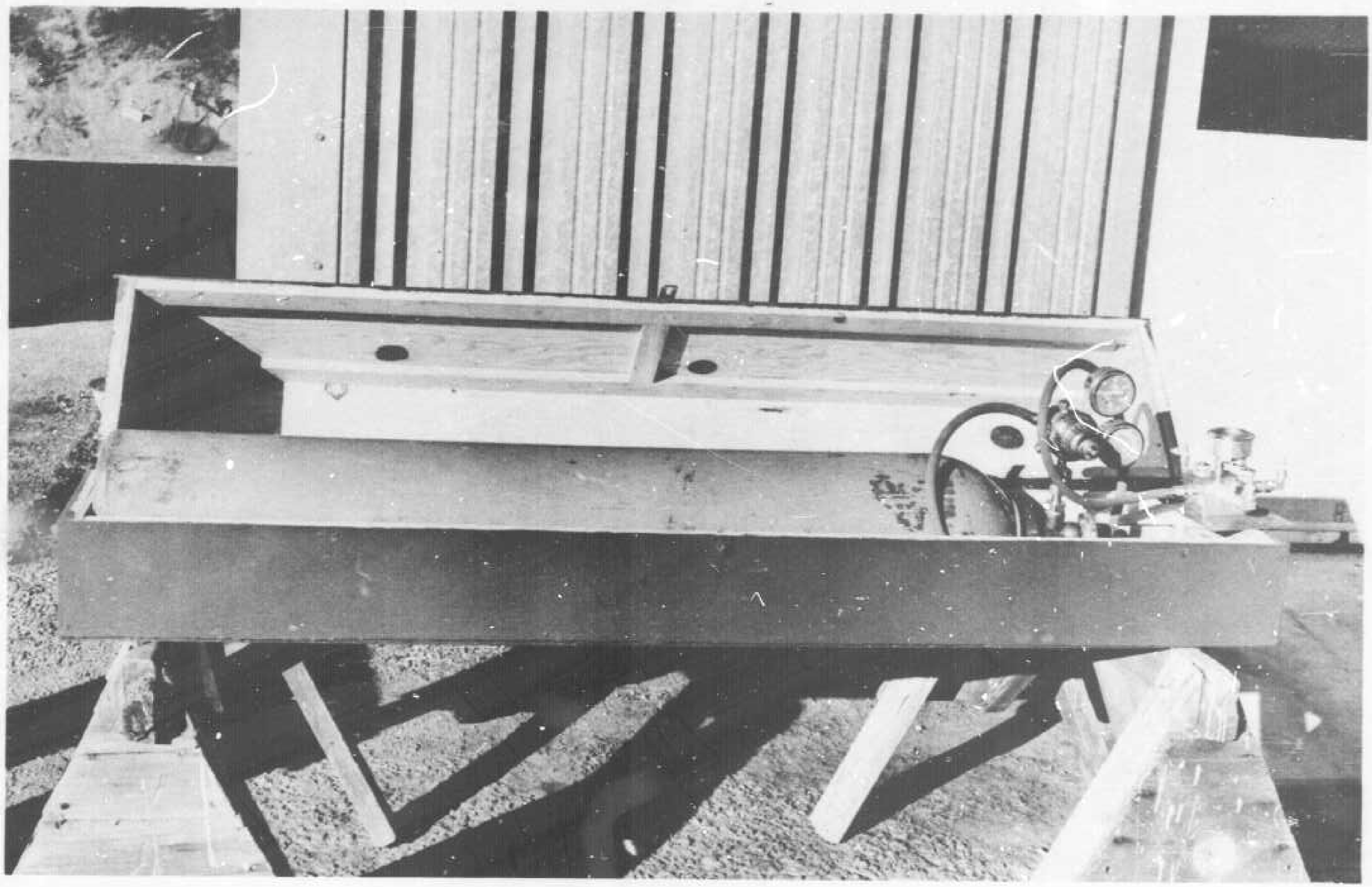


Figure 29. Dry nitrogen tank, controls and gauges mounted in box prior to installation at LP7, TFSO

installation, each tank vault was pressurized to 5 psi of nitrogen and its seal broken to release this pressure and purge the tank vault interior. The tank vault seal was then restored and the tank was pressurized with 1 psi of nitrogen.

From 22 November to 18 December, 160 cu ft, the entire contents of the (partially full) supply tank were used. As this rate of usage, 6.4 cu ft per day, was much greater than anticipated, all seals were retested and a defective one was repaired. Our objective was to reduce the nitrogen usage to about 1.5 cu ft per day, so that a 300 cu ft tank would furnish gas for 6 months. Long-term testing of this installation is continuing.

6.7 FLAG TRACES

Three high-magnification seismograms, routinely recorded at TFSO, serve as flag traces and are used in analysis work to detect low-amplitude arrivals. As these seismograms are produced by summing and filtering data from eight seismographs in the crossed linear array, and that array is used for no other purpose, a study was undertaken to determine if suitable flag traces could be produced using data from the 37-element short-Period array. In general, the study results indicated that flag traces using 37-element array data would be quite inferior to those using crossed linear array data. A copy of the letter report on this subject submitted to the Project Officer on 4 November 1969 is included in appendix 2.

6.8 LIGHTNING PROTECTION

Annual tests of all AEI lightning protectors in service at TFSO were conducted between March and August of this year. Of 232 units tested, 100 (43 percent) were found defective and were replaced. By comparison, 77 percent of the units tested during 1968 were found defective and were replaced.

6.9 MULTICONDUCTOR CABLE

During December 1968, a 5000-foot length of shielded 12-conductor cable was substituted for Spiral-4 cable in each of two cable runs in the short-period array. Both lengths were installed in areas of high lightning activity to compare their field performances with that of Spiral-4 cable. Short-period data from channels Z13, Z28, and Z29 were routed through one section and from channels Z10, Z23, and Z24 through the other section.

The section carrying channels Z13, Z28, and Z29 has operated without failure since its installation. The other section has suffered partial failures. At different times, from 2 to 4 conductors have shorted together. Since February, only the Z10 and Z24 data have passed through the 12-conductor cable. It has been necessary to route Z23 data through a separate Spiral-4 cable. The causes of the multiconductor cable failures are unknown. There has been no known lightning in the failure area, and there is no visible damage to the cable exterior.

7. ASSISTANCE PROVIDED TO OTHER GROUPS

7.1 TELEMETRY TO MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Data from seven seismographs were telemetered to the Massachusetts Institute of Technology Lincoln Laboratories throughout the year. The data transmitted were Z60, E60, N60, Z1LP, E47BF, Z47BF, and N47BF. The center frequency of all the circuits was adjusted when requested by MIT.

7.2 THE UNIVERSITY OF UTAH

A copy of each daily event record sent to ESSA-C&GS, was also sent to Dr. Kenneth Cook at the University of Utah.

7.3 TEXAS INSTRUMENTS INC.

Mr. Jack D. Woodham and the Texas Instruments Inc. (TI) digital recording van arrived at TFSO on 22 January 1969. On 24 January 1969, Mr. Leo Heiting arrived and recording of selected MCF processed data from the short-period and long-period arrays was begun. Recording was discontinued on 4 February 1969, but was resumed on 19 February after TFSO corrected malfunctions in several noisy long-period instruments. TI continued recording TFSO data until 5 March 1969.

7.4 UNIVERSITY OF CALIFORNIA, SAN DIEGO

University of California representatives, Mr. Bill Farrell and Mr. Don Miller, arrived on 10 February 1969 and Dr. Richard Haubrick arrived on 12 February to collect data for determining the effects of tidal loading in the TFSO area. Since 14 February they have recorded data from a JM seismometer, modified for displacement response; a gravity meter, and intermittently recorded data from several TFSO seismographs. Space for their recorders and instruments was provided in the west walk-in vault. Mr. Farrell and Mr. Miller have visited TFSO periodically throughout this interval to collect data and to maintain their equipment. TFSO personnel have assisted the group by routinely inspecting the recorders and instruments for proper operations.

7.5 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Keith Westhusing and Mr. Robert Bechtold, both of Lockheed - NASA, Houston, Texas, arrived at TFSO on 29 March with the NASA Mobile Geophysical Laboratory, installed seismic instruments in the east walk-in vault and started operations. Data from several of their instruments and from the TFSO LP1 system were recorded until late June. Mr. Bechtold and a co-worker of his, Mr. George Powasnick, visited TFSO alternately during the recording period to monitor instrument performance. All personnel and equipment departed on 26 June 1969.

Mr. Moyer and Mr. Schmidtt, NASA, Washington, D.C., tested their Mars seismograph at TFSO on 22 August 1969. Their data were recorded simultaneously with data from the TFSO Z47BF seismograph.

7.6 UNIVERSITY OF CALIFORNIA, LOS ANGELES

On 22 and 23 August 1969, Mr. C. L. Hager and Mr. Eric Syrstad, of the University of California at Los Angeles, set up earth tide recording equipment in the observatory engineering laboratory and collected data for Dr. Louis B. Slichter, UCLA Space Science Center. The system was operated unattended except for periodic circuit balancing by TFSO personnel, and was removed on 24 September 1969.

7.7 VISITORS

7.7.1 Visits by VELA Seismological Center Personnel

Captain Fred Munzlinger, VSC Project Officer, visited TFSO from 13 through 17 January 1969 to discuss observatory work planned for the contract period.

Captain Fred Munzlinger, departing VSC Project Officer, and Lieutenant John H. Fergus, the new VSC Project Officer, visited the observatory on 10 and 11 April 1969.

Dr. Frank Pilotte, VSC, escorted visitors at TFSO on 13 May 1969. The visitors included Mr. D. C. Clements, ARPA; W. A. Gallif, Hqs./OAR; Major D. D. Young, USAF; M. J. Kerper, USAF/OAR; and Mr. William Best, USAF/OAR.

7.7.2 Teledyne Visitors

Mr. Brad Leichliter, Geotech Program Manager, visited TFSO from 13 through 15 January 1969, to discuss observatory work planned for the contract period. Mr. Leichliter visited TFSO again 10 and 11 April 1969 while escorting the new Project Officer on an orientation tour.

Mr. R. A. Arnett, Geotech President, and Mr. J. L. Wood, Geotech Administrative Vice-President, were visitors at TFSO on 23 June 1969.

Mr. Jack Hamilton, Teledyne, and Mr. R. A. Arnett, Geotech President, visited TFSO 26 and 27 October 1969.

Mr. Martin Gudzin, Geotech Program Engineer, visited TFSO 25 through 28 March and 9 through 11 September 1969, to coordinate engineering work and special tests.

7.7.3 Visits by School Groups

From 1 January to 31 December 1969, approximately 672 students and instructors from Arizona State University visited TFSO in several groups. During the same time period, four groups of high school students from Phoenix and Payson, Arizona, area visited TFSO. All visitors were given tours of the observatory and brief lectures about seismology.

7.7.4 Others

Mr. Lowell DeJong, 3M Company, visited TFSO on 18 February 1969 to investigate our complaints of unsatisfactory performance of 3M magnetic tape on TFSO recorders.

Mr. Jesse E. King and Miss Linnea Poulsen, Central Intelligence Agency (CIA), toured the observatory and several field sites on 14 July 1969 to collect information to be used in a CIA study.

Mr. C. P. Smith and Mr. Les Jackson, U. S. Forest Service, visited TFSO on 16 May 1969 to coordinate USFS rehabilitation work within the TFSO arrays with station operation.

Dr. R. Blandford, Geotech-SDL, visited TFSO 15 December 1969 to become familiar with and to discuss observatory operations.

Mr. Phillips and Mr. Kiliner, Empire Machinery, visited TFSO 3 December 1969 to discuss the requirements for an automatic switchover emergency power system.

8. REPORTS AND DOCUMENTS PUBLISHED UNDER PROJECT VT/9702

8.1 TECHNICAL REPORTS

The following technical reports were published and distributed in accordance with the requirements of Project VT/9702.

a. Technical Report No. 69-2, Preliminary Study of TFSO Short-Period and Long-Period Noise Fields;

b. Technical Report No. 69-16, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 1, Project VT/9702, 1 January through 31 March 1969;

c. Technical Report No. 69-27, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 2, Project VT/9702, 1 April through 30 June 1969;

d. Technical Report No. 69-48, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 3, Project VT/9702, 1 July through 30 September 1969.

8.2 LETTER REPORTS

The following letter reports were submitted to the Project Officer:

a. "Evacuated Long-Period Seismometer," dated 10 June 1969;

b. "Extended Long-Period Seismographs at TFSO and Garland," dated 22 August 1969;

c. "Effect of Sampling Rate on Digitally Recorded Seismic Signals," dated 25 September 1969;

d. "Flag Traces at TFSO," dated 4 November 1969;

e. "Extended Long-Period Seismographs," dated 1 October 1969.

APPENDIX 1 to TECHNICAL REPORT NO. 70-1

STATEMENT OF WORK TO BE DONE

4 Oct 1968

STATEMENT OF WORK TO BE DONE
(AFTAC Project Authorization No. VELA T/9702/S/ASD) (32)

Tasks:

a. Operation:

(1) Continue operation of the Tonto Forest Seismological Observatory (TFSO), normally recording data continuously.

(2) Evaluate the seismic data to determine optimum operational characteristics and make changes in the operating parameters as may be required to provide the most effective observatory possible. Addition and modification of instruments are within the scope of work. However, such instrument modifications and additions, data evaluation, and major parameter changes are subject to the prior approval of the AFTAC project officer.

(3) Conduct routine daily analysis of seismic data at the observatory and transmit daily seismic teletype reports to the Coast and Geodetic Survey, Environmental Science Services Administration, Washington Science Center, Rockville, Maryland, using the established report format and detailed instructions.

(4) Establish quality control procedures and conduct quality control, as necessary, to assure the recording of high-quality data on both magnetic tape and film. Past experience indicates that a quality control review of one magnetic tape per magnetic tape recorder at the observatory during each week is satisfactory unless quality control tolerances have been exceeded and the necessity of additional quality control arises. Quality control of magnetic tape should include, but need not necessarily be limited to, the following items:

(a) Completeness and accuracy of operation logs.

(b) Accuracy of observatory measurements of system noise and equivalent ground motion.

(c) Quality and completeness of voice comments.

(d) Examination of all calibrations to assure that clipping does not occur.

(e) Determination of relative phase shift on all array seismographs.

(f) Measurement of DC unbalance.

(g) Presence and accuracy of tape calibration and alignment.

(h) Check of uncompensated noise on each channel.

Atch 1

(i) Check of uncompensated signal-to-noise of channel 7.

(j) Check of general strength and quality of timing data derived from National Bureau of Standards Station WWV.

(k) Check of time pulse modulated 60 cps on channel 14 for adequate signal level and for presence of time pulses.

(l) Check of synchronization of digital time encoder with WWV.

(5) Provide observatory facilities, accompanying technical assistance by observatory personnel, and seismological data to requesting organizations and individuals after approval by the AFTAC project officer.

(6) Maintain, repair, protect, and preserve the facilities of TFSO in good physical condition in accordance with sound industrial practice.

b. <u>Instrument Evaluation</u>: On approval by the AFTAC project officer, evaluate the performance characteristics of experimental or off-the-shelf equipment offering potential improvement in the performance of observatory seismograph systems. Operation and test of such instrumentation under field conditions should normally be preceded by laboratory test and evaluation.

c. <u>Special Investigations</u>:

(1) Conduct research investigations as approved or requested by the AFTAC project officer to obtain fundamental information which will lead to improvements in the detection capability of TFSO. These programs should take advantage of geological, meteorological, and seismological conditions of the observatory.

(2) Investigations may be conducted in, but not necessarily limited to, the following areas of interest: microseismic noise, signal characteristics, data presentation, detection threshold, and array design (surface and shallow borehole).

(3) Prior to commencing any research investigation, AFTAC approval of the proposed investigation and of a comprehensive program outline of the intended research must be obtained.

APPENDIX 2 to TECHNICAL REPORT NO. 70-1

LETTER REPORT ON "FLAG TRACES AT TFSO"

BLANK PAGE

4 November 1969

HQ USAF (AFTAC/VELA
Seismological Center)
Washington, D.C. 20333

Attention: Lt. John H. Fergus

Subject: Flag traces at TFSO

Gentlemen:

Data from selected elements in the crossed-linear short-period (SP) array at TFSO are routinely summed, filtered and recorded to produce three flag seismograms: ΣT, ΣTF, and ΣTFK. The simple summation channel, ΣT, is normally recorded at a magnification of approximately 1200K, and the filtered summation channels, ΣTF and ΣTFK, at magnifications of approximately 6500K at 1 cps. These extra-high magnification channels are used in routine analysis work to detect low-amplitude arrivals which might not be discernible on lower gain seismograms.

Eight seismographs in the crossed-linear array are operated and maintained only to obtain data for the three flag seismograms; these data are not used for any other purpose. If suitable flag seismograms could be produced with data from the 37-element SP array, the crossed-linear array could be deactivated, and the work load at TFSO could be reduced. The feasiblity of accomplishing this was investigated from February to July 1969, when data from selected elements in the 37-element SP array were summed, filtered, and recorded to produce five new flag seismograms. These (ΣX, ΣXFK, ΣNWF, ΣNEF and ΣEWF) were studied and compared with the original three flag seismograms to determine if use of the crossed-linear array could be discontinued without reducing the detection capability of TFSO.

The following is an identification of all flag seismograms used in this study:

ΣT	- Z61, Z62, Z64, Z65, Z68, Z70, Z71, Z72	(unfiltered)
ΣTF	- Z61, Z62, Z64, Z65, Z68, Z70, Z71, Z72	(UED filter)
ΣTFK	- Z61, Z62, Z64, Z65, Z68, Z70, Z71, Z72	(Krohn-Hite filter)
ΣX	- Z1, Z2, Z3, Z4, Z5, Z6, Z7	(unfiltered)
ΣXFK	- Z1, Z2, Z3, Z4, Z5, Z6, Z7	(Krohn-Hite filter)
ΣNWF	- Z1, Z2, Z5, Z8, Z14, Z20, Z29	(TFSO filter)
ΣNEF	- Z1, Z3, Z6, Z10, Z16, Z23, Z32	(TFSO filter)
ΣEWF	- Z1, Z4, Z7, Z12, Z18, Z26, Z35	(TFSO filter)

Seismometer locations are shown in figure 1; seismograph frequency responses are shown in figure 2.

Flag seismograms were recorded at magnifications limited only by microseismic background. Channels with filters best able to discriminate against this background (which has a frequency of approximately 0.167 cps) were operated at the highest magnifications. ΣTF, ΣTFK, and ΣXFK operated at approximately 6500K; ΣNWF, ΣNEF, and ΣEWF operated at approximately 2500K, and ΣT and ΣF (unfiltered) operated at approximately 1200K.

Figures 3 through 13 show seismograms typical of those made during the recording period. The following is additional information concerning these recordings:

Figure 3. Recording of an event about 70 degrees ENE of TFSO. ΣTFK responds to amplitude greater than ΣXFK by a factor of about 2. Note ΣXFK is recording through filter normally used for ΣTFK, and ΣTFK is recording through filter normally used for ΣXFK.

Figure 4. Recording of an event 130 degrees NE of TFSO. Note equal amplitude response of ΣTFK and ΣXFK. Also, the linear array summations respond equally. ΣTFK is recording through filter normally used for ΣXFK and ΣXFK is recording through filter normally used for ΣTFK.

Figure 5. Recording of an event about 79 degrees NW of TFSO. The event amplitude on ΣTFK is twice the event amplitude on ΣXFK. The signal is broadside to some of the elements composing ΣTFK. Note the large amplitude on ΣNEF.

Figure 6. Recording of an event about 80 degrees SW of TFSO. ΣTFK responds with only slightly higher amplitude than ΣXFK. This is due to epicenter being in line with most of the elements composing ΣTFK. Note the amplitude recorded on ΣNWF.

Figure 7. Recording of an event about 72 degrees SE of TFSO. ΣTFK responds to amplitude greater than ΣXFK. Note the amplitude of the ΣNEF trace.

Figure 8. Recording of an event 46 degrees NW of TFSO. ΣTFK responds to signal with amplitude greater than ΣXFK by a factor of about 2.

Figure 9. Recording of an event about 27 degrees SE of TFSO. ΣTFK responds to signal with amplitude greater than ΣXFK by a factor of more than 3.

Figure 10. Recording of an event about 118 degrees SW of TFSO. Note that ΣXFK, ΣTFK, and the linear summations recorded this signal with about equal amplitudes.

Figure 11. Recording of an event 124.5 degrees SW of TFSO. Note equal amplitude response of ΣTFK and ΣXFK. ΣXFK is not attenuated because array is causing very little cancelling effect due to the apparent velocity (angle of incidence very steep) being so fast. Also note that the linear array summations respond with similar amplitudes due to the steepness of the angle of incidence.

Figure 12. Recording of a teleseismic event with unknown epicenter. Event is probably P^1 (110 degrees or greater) distance since ΣTFK and ΣXFK respond with equal amplitude and also the linear array summations respond with similar amplitudes.

Figure 13. Recording of a teleseismic event with unknown epicenter. ΣT and ΣTFK respond to amplitudes greater than ΣX and ΣXFK, respectively, by a factor greater than 5.

Data taken from the seismograms indicate that ΣX and ΣXFK respond as well as do ΣT and ΣTFK for events approximately 100 or more degrees away, but do not respond as well to closer events. At a distance of 25 degrees, the responses differ by a factor of 4. The seismograms also show that signals from events at all distances, and arriving broadside to the ΣNWF, ΣNEF and ΣEWF arrays are received with amplitudes that are very nearly equal to those received by ΣT and ΣTFK. These observations indicate that flag traces made by simply summing selected elements of the 37-element SP array are far more limited in their detection capabilities than those made from summing elements of the crossed-linear array.

In order to better understand the parameters involved in establishing a useful flag trace, expressions for array directivity were derived and plots were made. Figure 14 shows the directivity pattern (zero degrees is broadside to the array) for a 7-element linear array like ΣNWF, ΣNEF, or ΣEWF where array elements are spaced 1/2 wavelength. Although the gain at the peaks of the two major lobes is seven times that of a single instrument, the array is sharply directional. Three such arrays, arranged at 60-degree intervals would give very poor azimuthal coverage, and in addition, would be extremely directional on a three-dimensional basis. Figures 16 and 17 show the directivity patterns for 5-element linear arrays. Note that the major lobes are broader, but still give poor azimuthal coverage. Figure 18 shows the directivity pattern as a function of angle of incidence, for the omnidirectional array ΣX. A wave arriving along a path normal to the earth's surface is considered to have a zero degree angle of incidence; one arriving along the earth's surface has 90 degrees. Figure 19 shows relative array gain as a function of incidence angle and figure 20 array gain as a function of great circle distance - based on published information that relates great circle distance to angle of incidence. Figures 21 through 23 show directivity patterns for the crossed-linear array. Note that it is very nearly omnidirectional for the most useful great circle distances. Also note that the element spacings are either 1/10 or 1/5 wavelength.

These data and observations lead to the following conclusions:

1. Simple summations of elements in the 37-element array, whether arranged as linear or omnidirectional arrays, will not produce flag traces as good as summations of elements in the linear array. The element spacing is too great (1/2 wavelength at signal frequencies) and produces a directivity pattern that looks at large areas of the earth with very low gain.

2. The filtered summation of 9 elements within the crossed-linear array (ΣTFK) produces the best flag trace that can be made using existing operational sites at TFSO. It has good azimuthal and great circle coverage.

3. A flag trace with better omnidirectional characteristics but slightly less gain than ΣTFK could be made by simply summing and filtering the outputs from a 7-element omnidirectional array whose elements are spaced 1/10 wavelength apart. Figure 24 shows the directivity of this array. Note the small gain variation over the great circle distances of interest and note that gain variations with azimuth are insignificant. Contrast this with figure 23.

We hope that this information will be of interest to you, and will be pleased to discuss it further.

Very truly yours,

B. B. Leichliter
Department Manager
Field Operations

BBL:ma

bcc: R. K. Rasmussen
G. M. Stanfill
M. G. Gudzin
D. R. Phillips
J. M. Ward

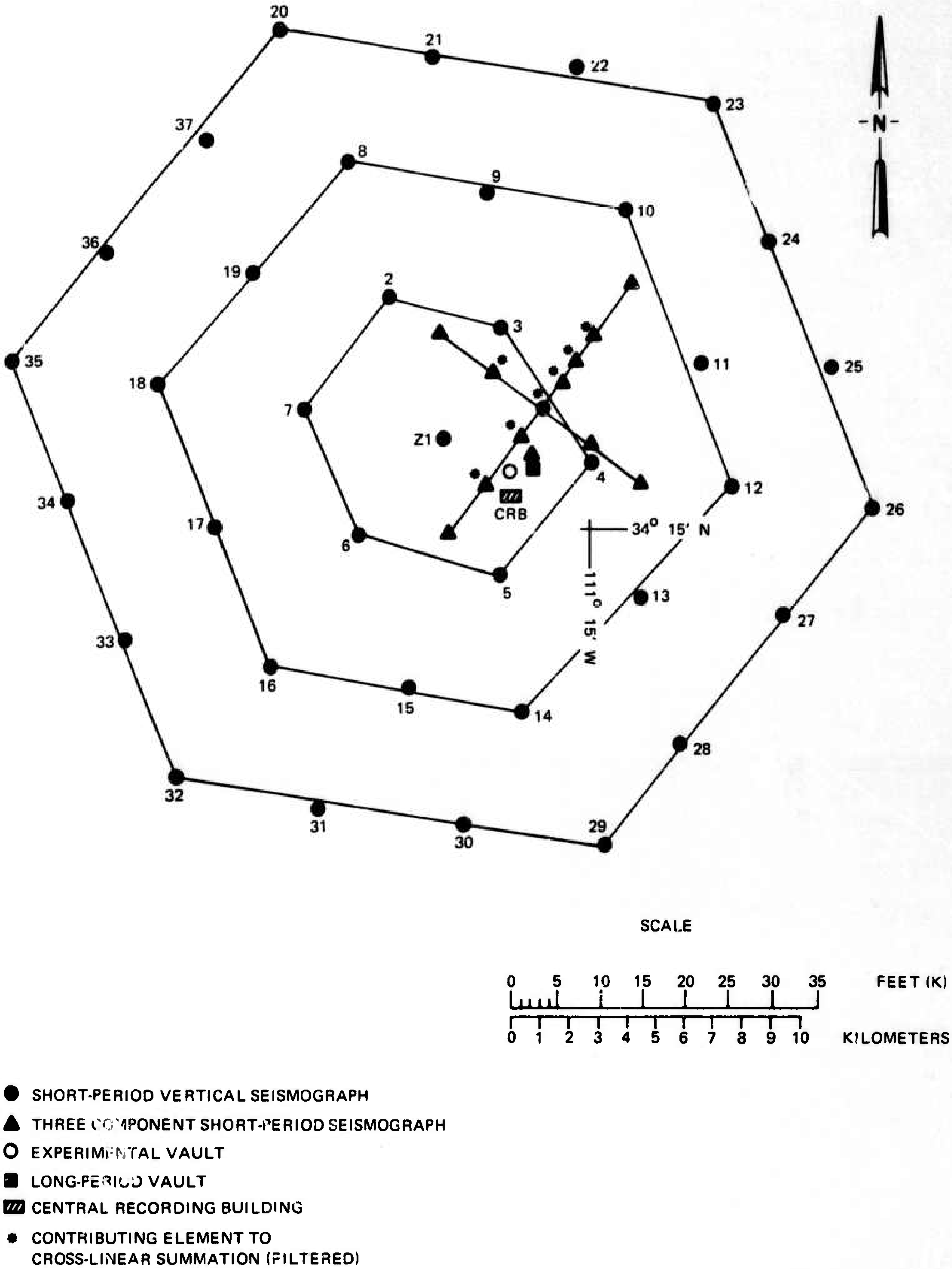


Figure 1. Tonto Forest Seismological Observatory 37-element and cross-linear arrays

G 4432

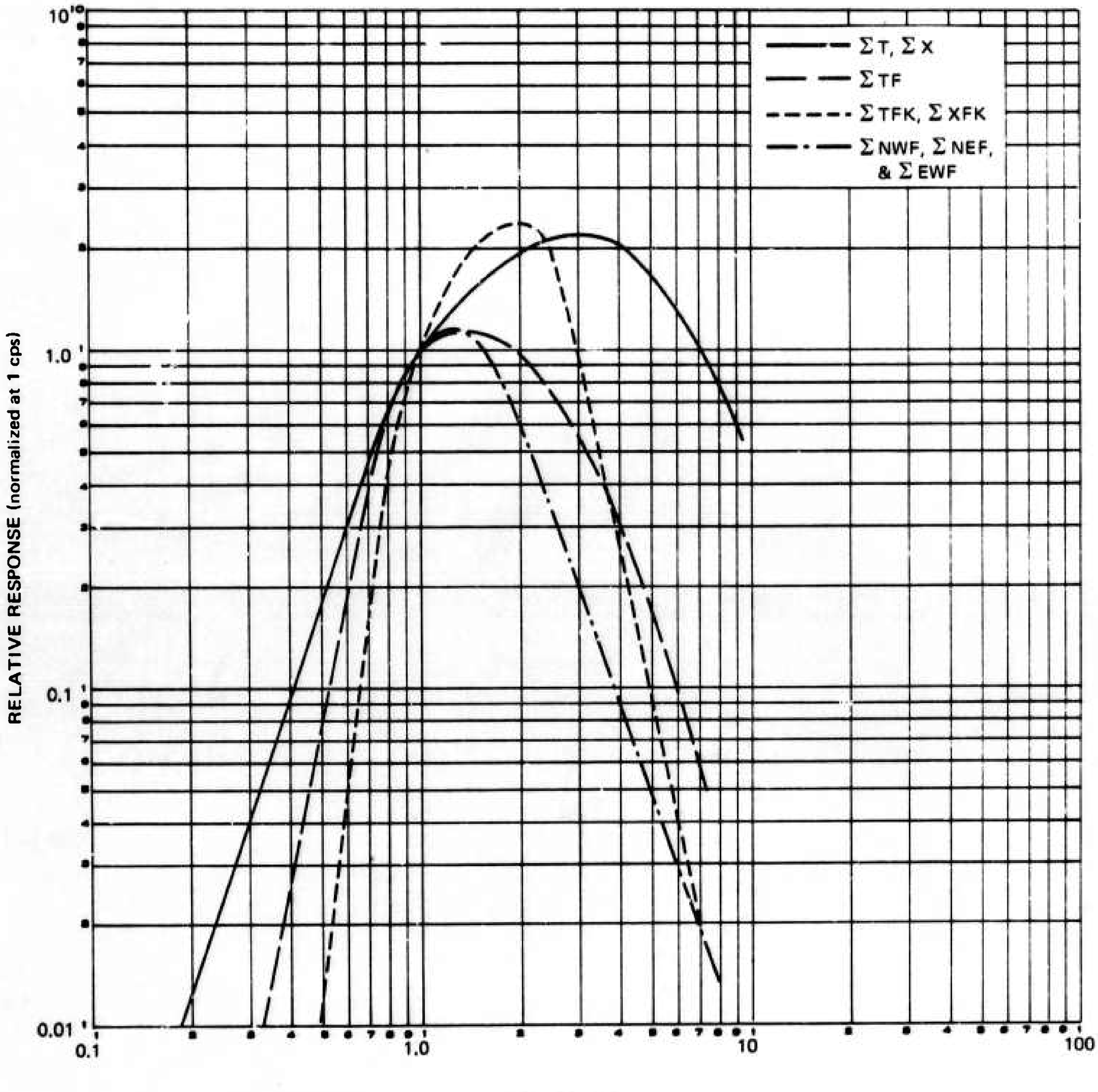


Figure 2. Normalized frequency responses of flag seismographs tested at TFSO

G 5536

TFSØ
10 May 1969
69-130

DEV. 9
Data Trunk 4
Data Group 7281

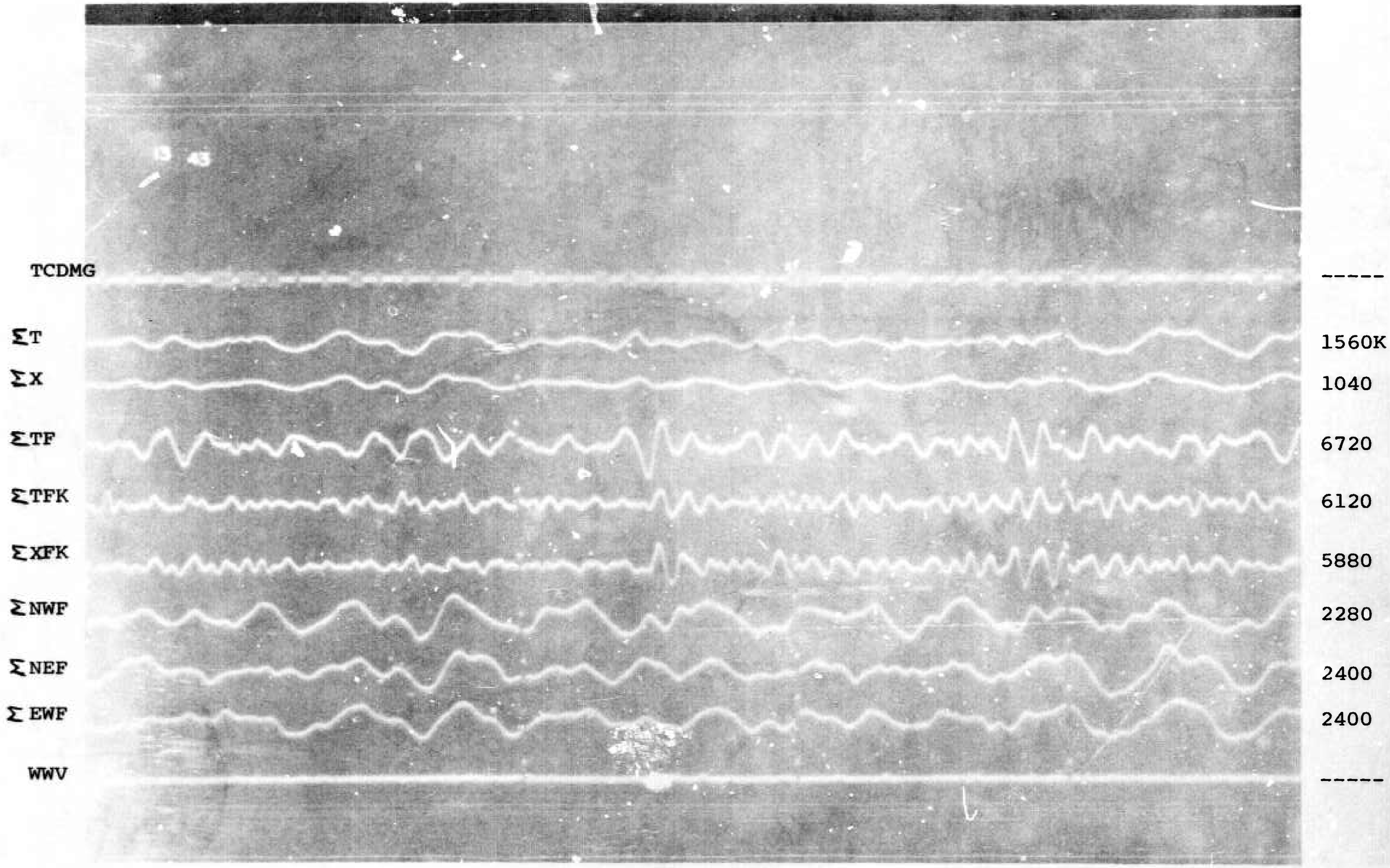


Figure 3. Origin = 13:31:15.0 Z Delta = 70.0 degrees
36.1 N - 10.8 W NORTH ATLANTIC OCEAN

TFSØ
11 May 1969
69-131

DEV. 9
Data Trunk 4
Data Group 7281

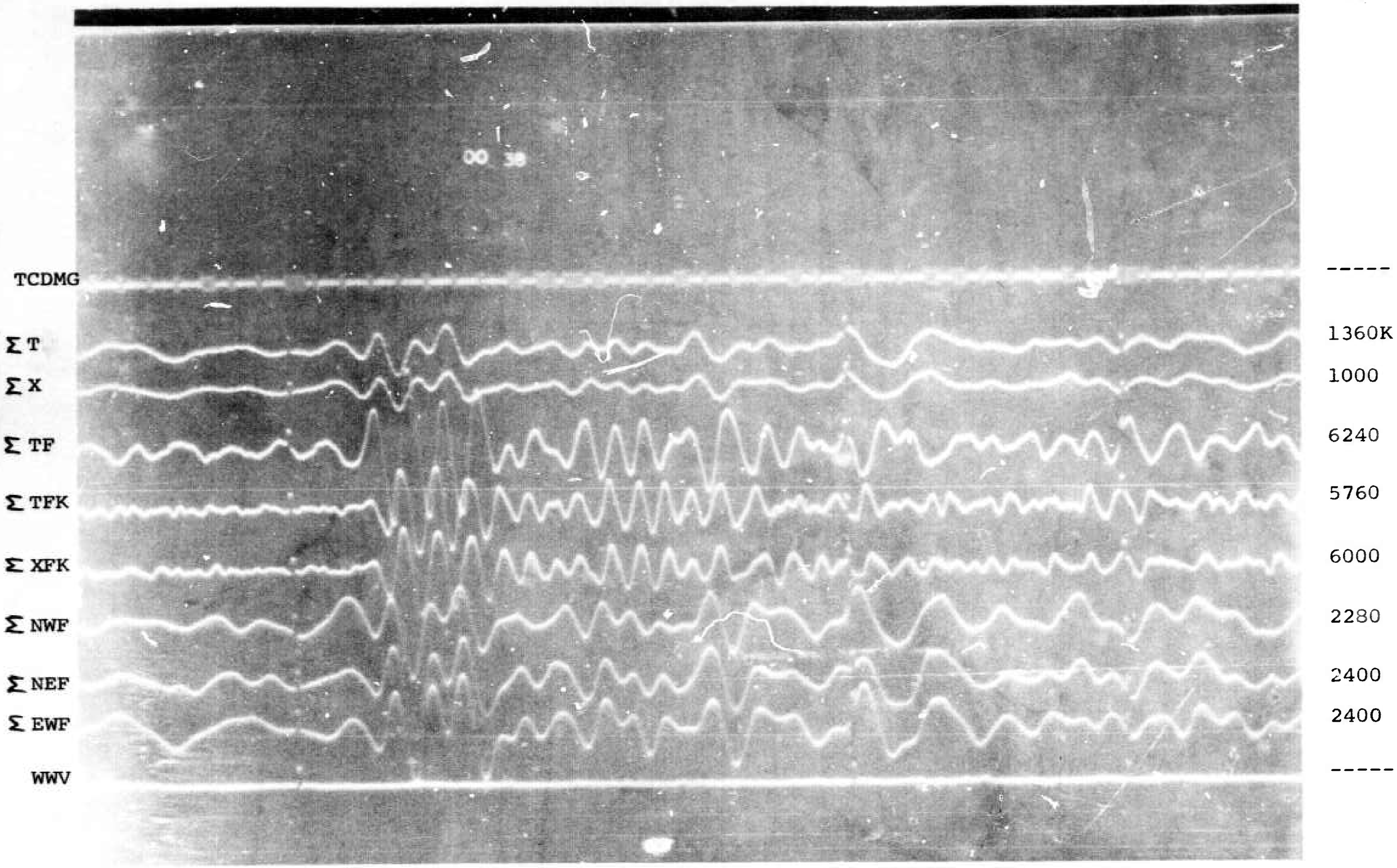


Figure 4. Origin = 00:18:41.9Z Delta = 130.3 degrees
14.3 N - 56.7 E ARABIAN SEA

TFSØ
02 May 1969
69-122

DEV. 9
Data Trunk 4
Data Group 7281

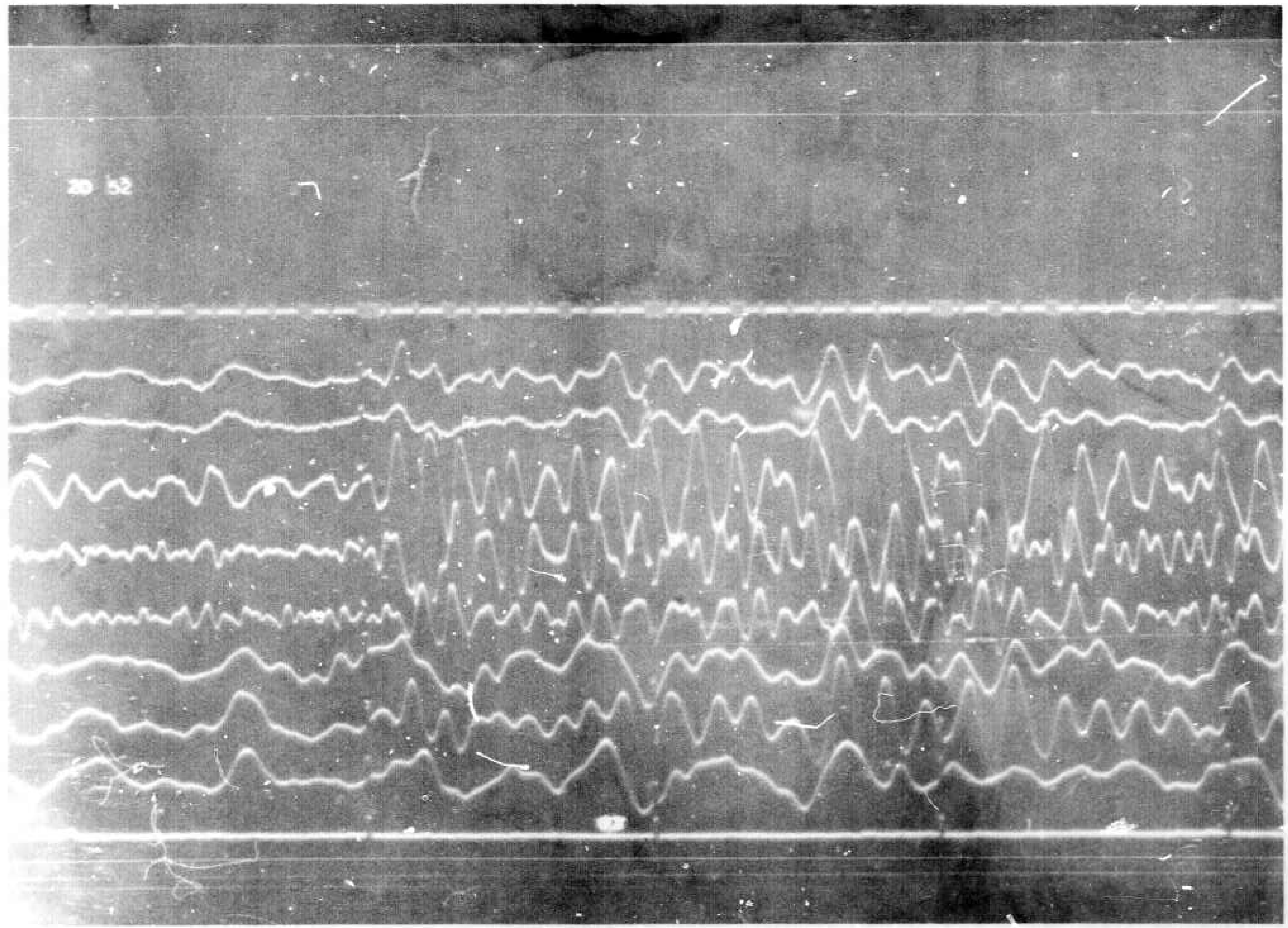


Figure 5. Origin = 20:40:11.3 Z Delta = 79 degrees
40.9 N - 140.3 W JAPAN

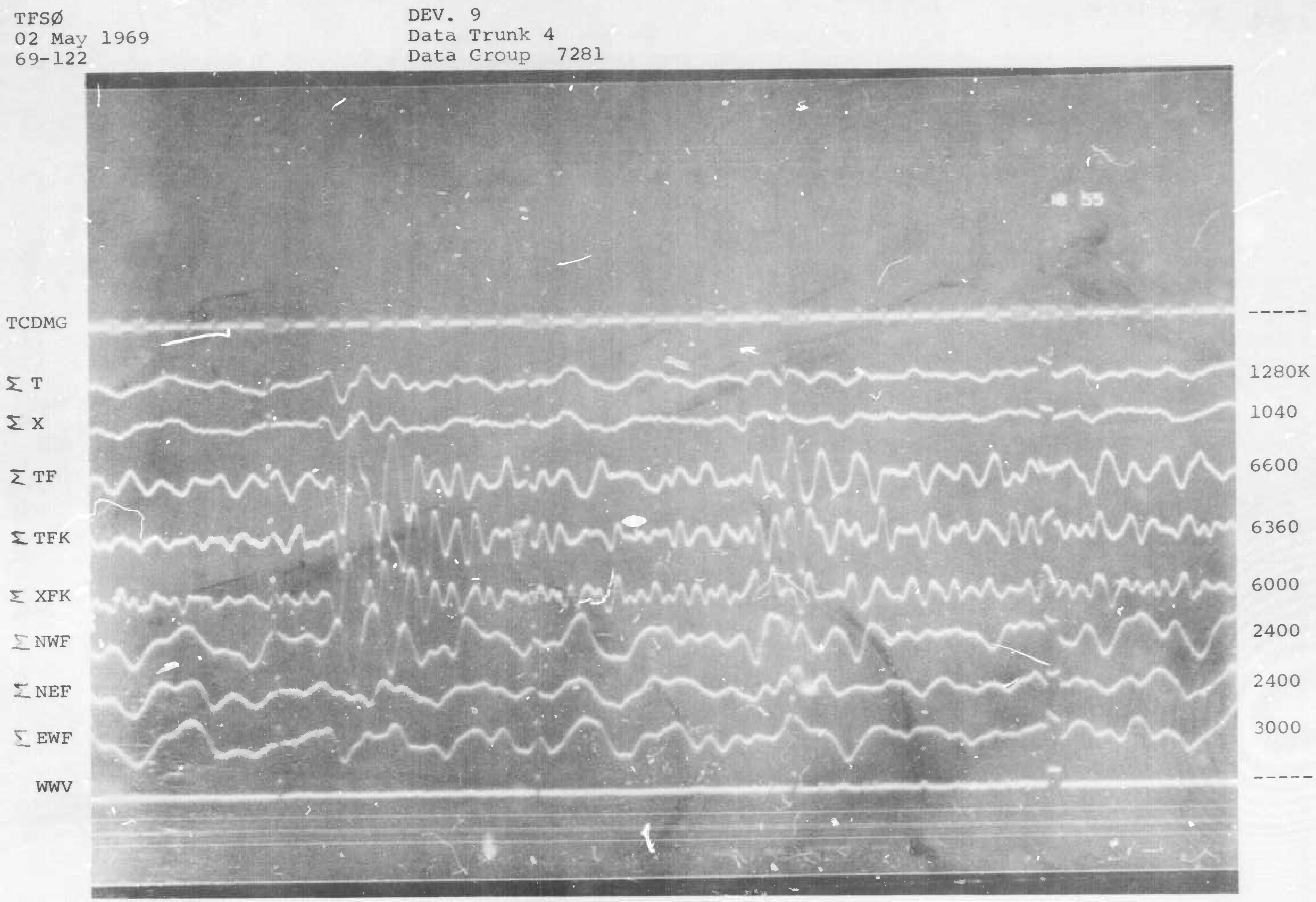


Figure 6. Origin = 18:42:22.3 Z Delta = 80 degrees
19.1 S - 174.6 W TONGA ISLAND

TFSØ
01 May 1969
69-121

DEV. 9
Data Trunk 4
Data Group 7281

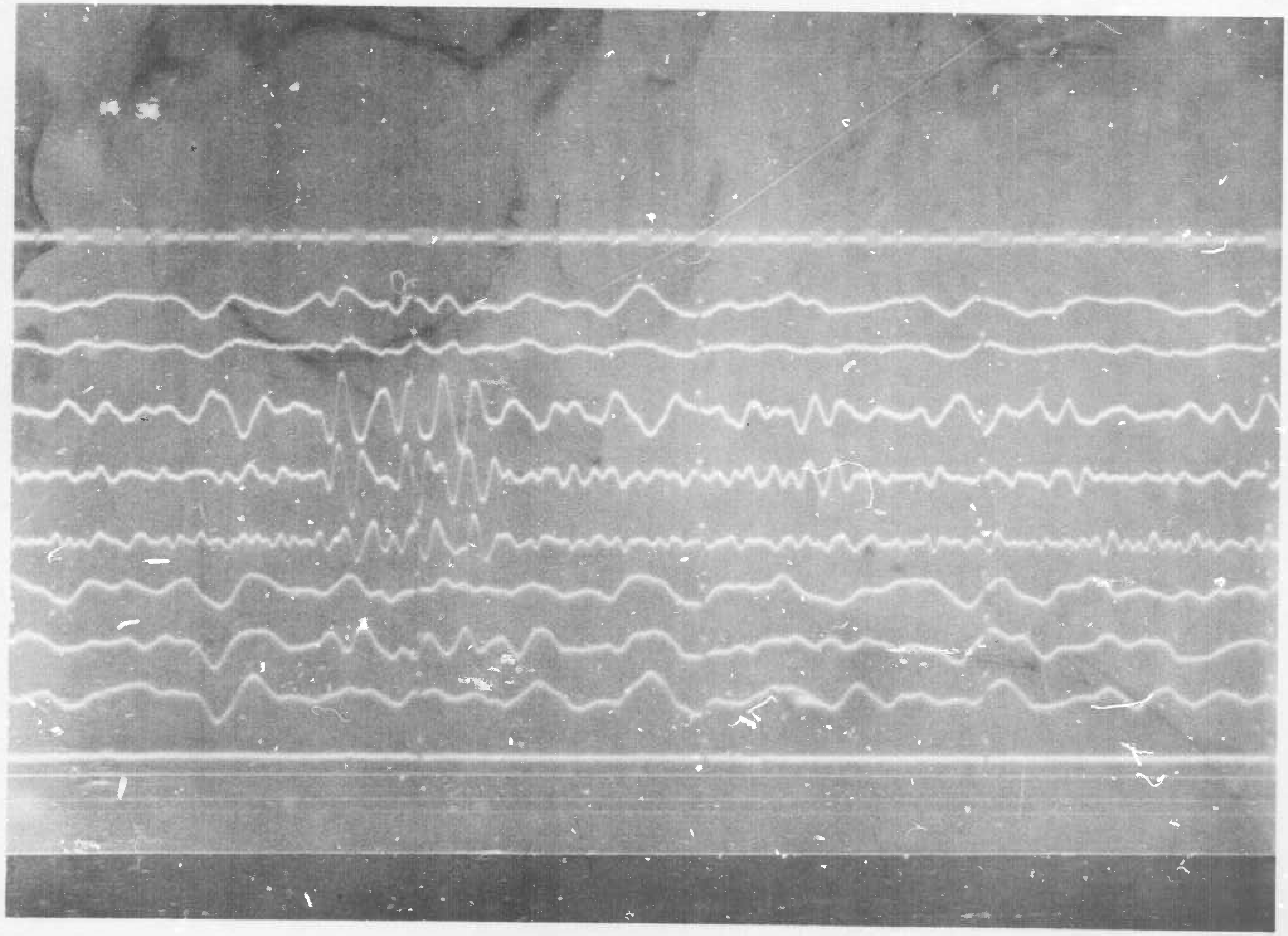


Figure 7. Origin = 14:24:48.0 Z Delta = 72 degrees
23 S - 65 W JUJUY PROVINCE ARGENTINA

TFSØ
03 May 1969
69-123

DEV. 9
Data Trunk 4
Data Group 7281

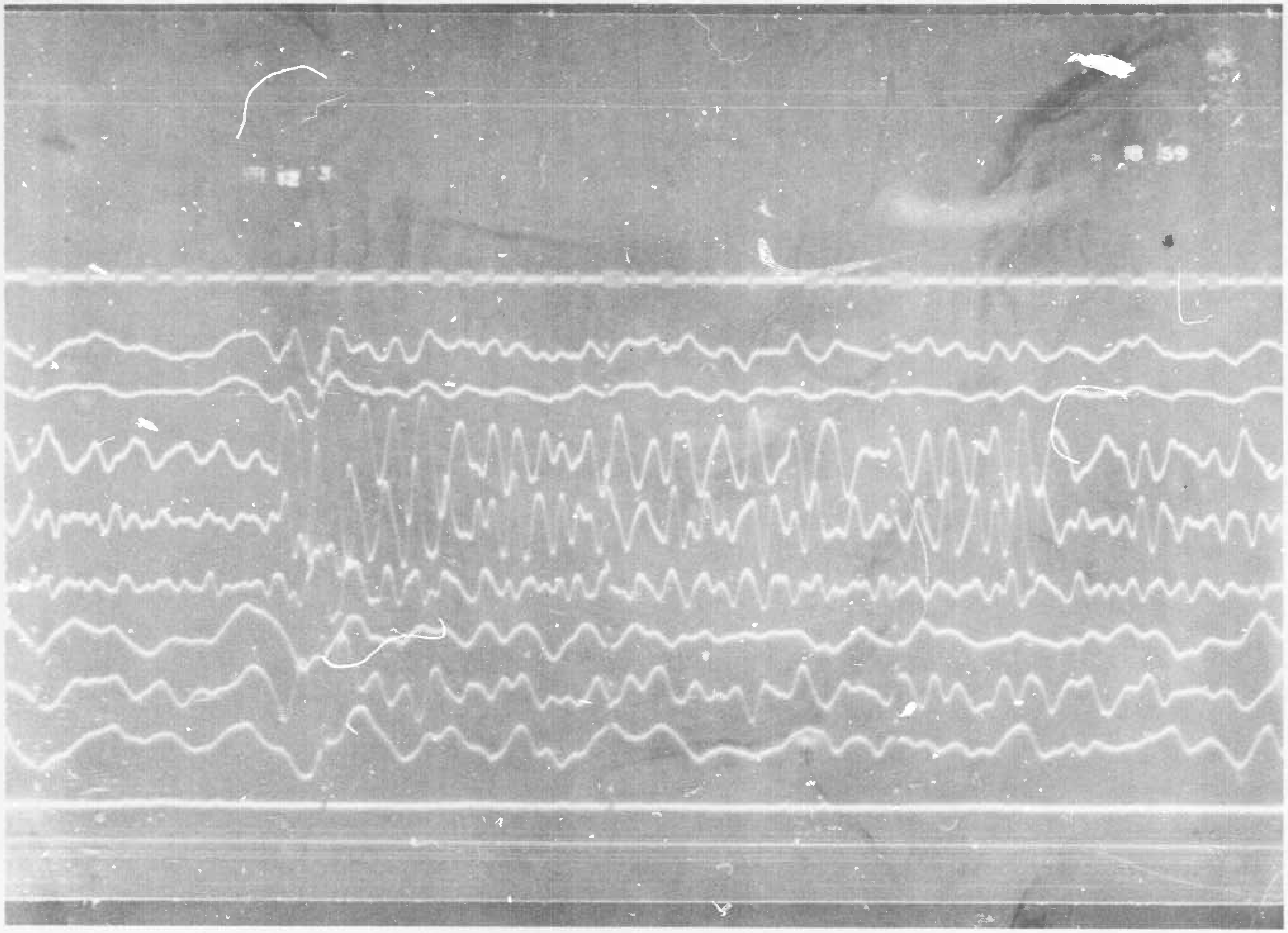


Figure 8. Origin = 18:50:09.6 Z Delta = 45.8 degrees
52.3 N - 171.2 W FOX ISLAND, ALEUTIAN ISLANDS

TFSØ
03 May 1969
69-123

DEV. 9
Data Trunk 4
Data Group 7281

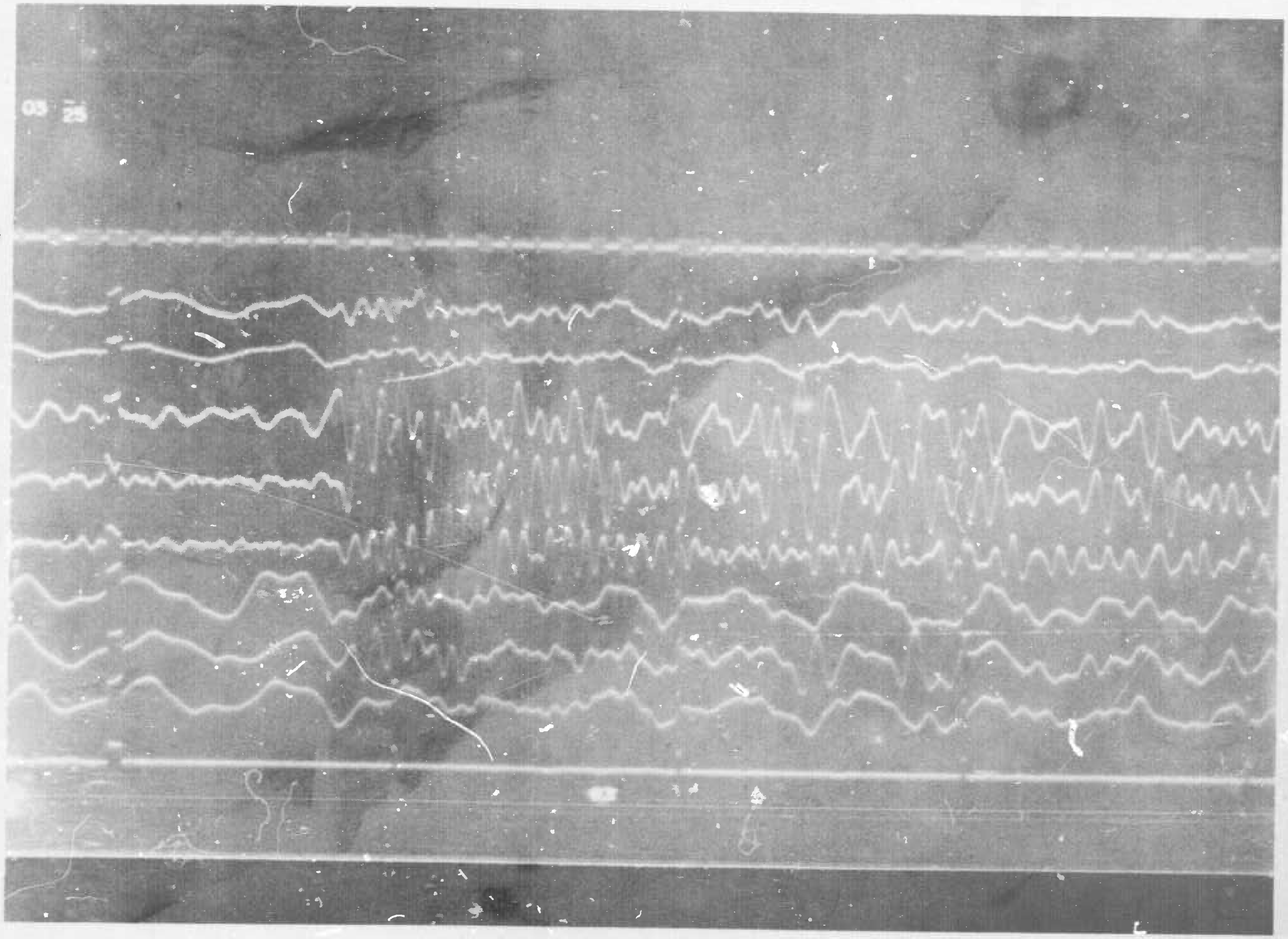


Figure 9. Origin = 03:19:06.3 Z Delta = 26.6 degrees
13.0 N - 88.4 W EL SALVADOR

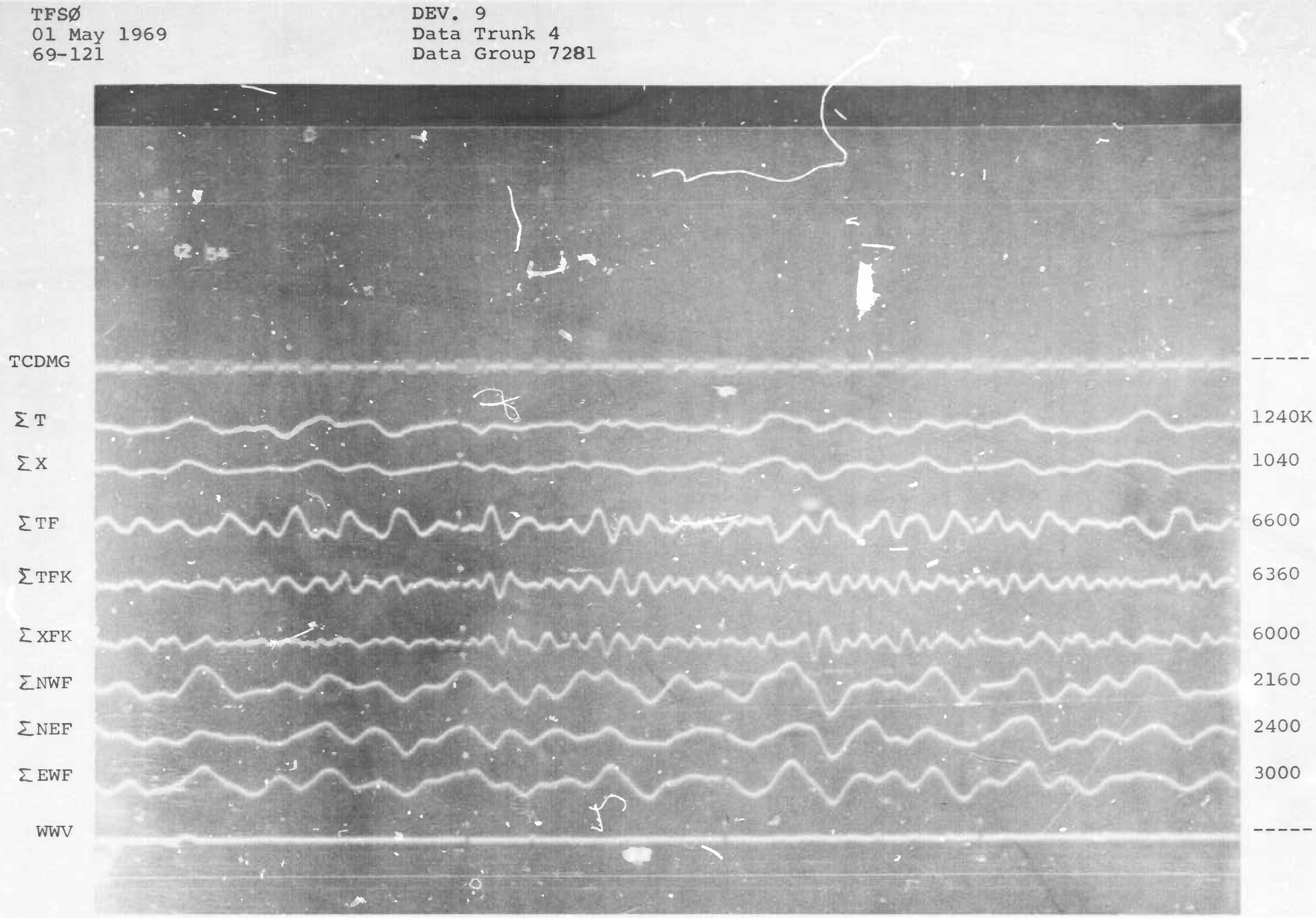


Figure 10. Origin = 12:35:30.2 Z Delta = 117.8 degrees
106°N - 123.1°E NORTH CELEBES SEA

TFSØ
05 May 1969
69-125

DEV. 9
Data Trunk 4
Data Group 7281

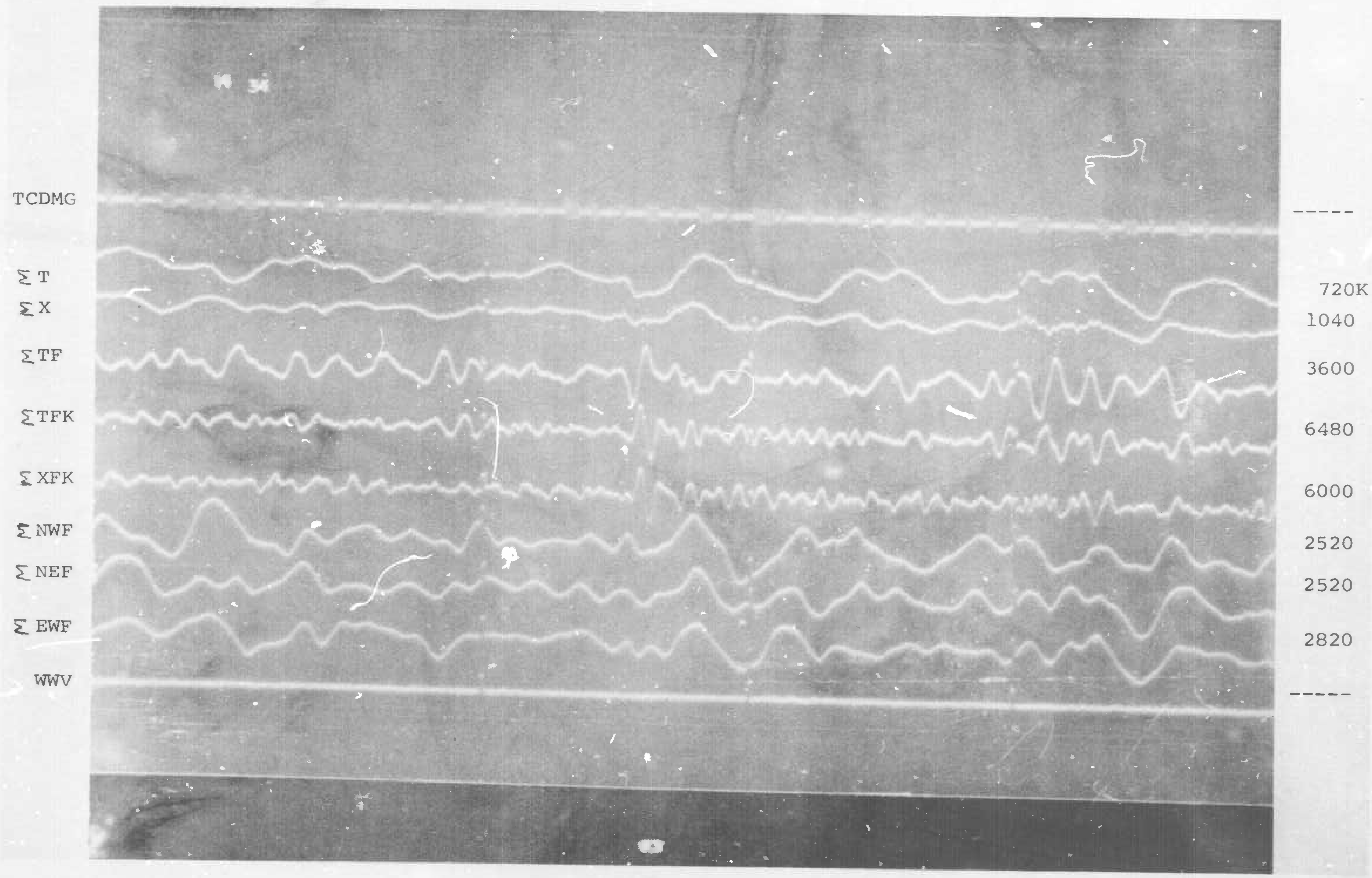


Figure 11. Origin = 14:15:16.9 Z   Delta = 124.5 degrees   h = 25 km
44.2 S - 141.4 E   SOUTH OF AUSTRALIA

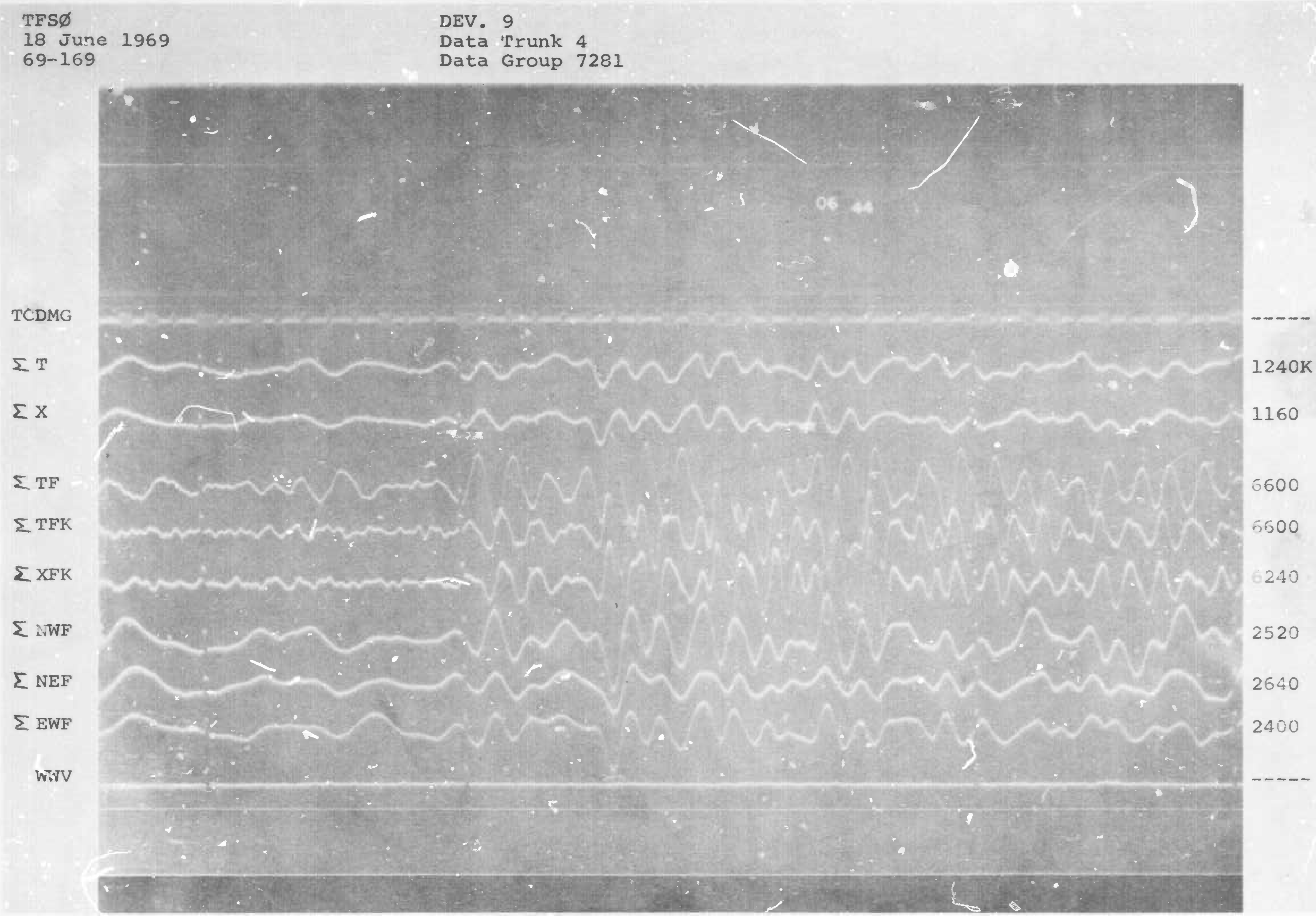


Figure 12. Short-period recording of a teleseismic event, epicenter unknown

TFSØ
18 June 1969
69-169

DEV. 9
Data Trunk 4
Data Group 7281

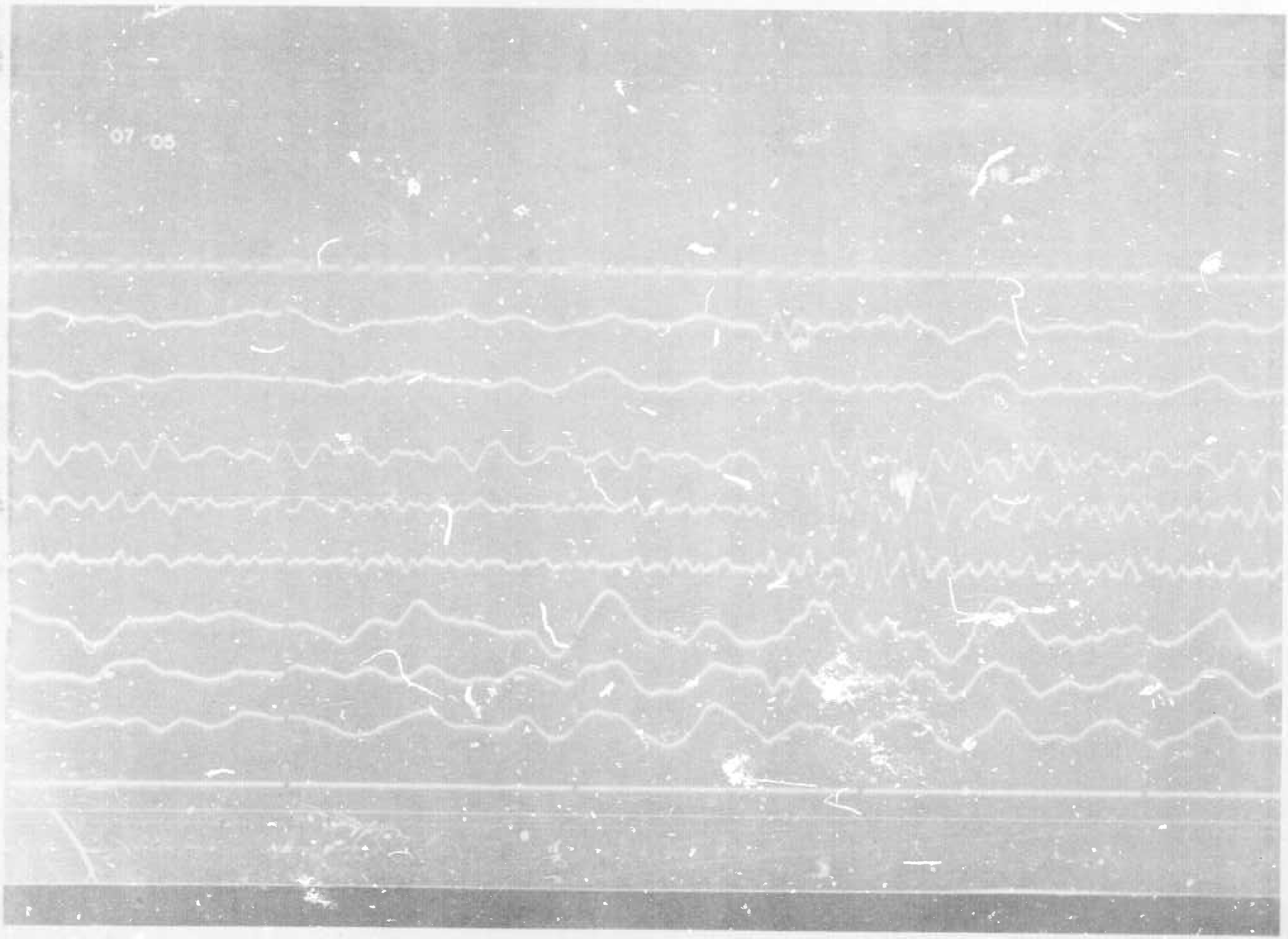


Figure 13. Short-period recording of a teleseismic event, epicenter unknown

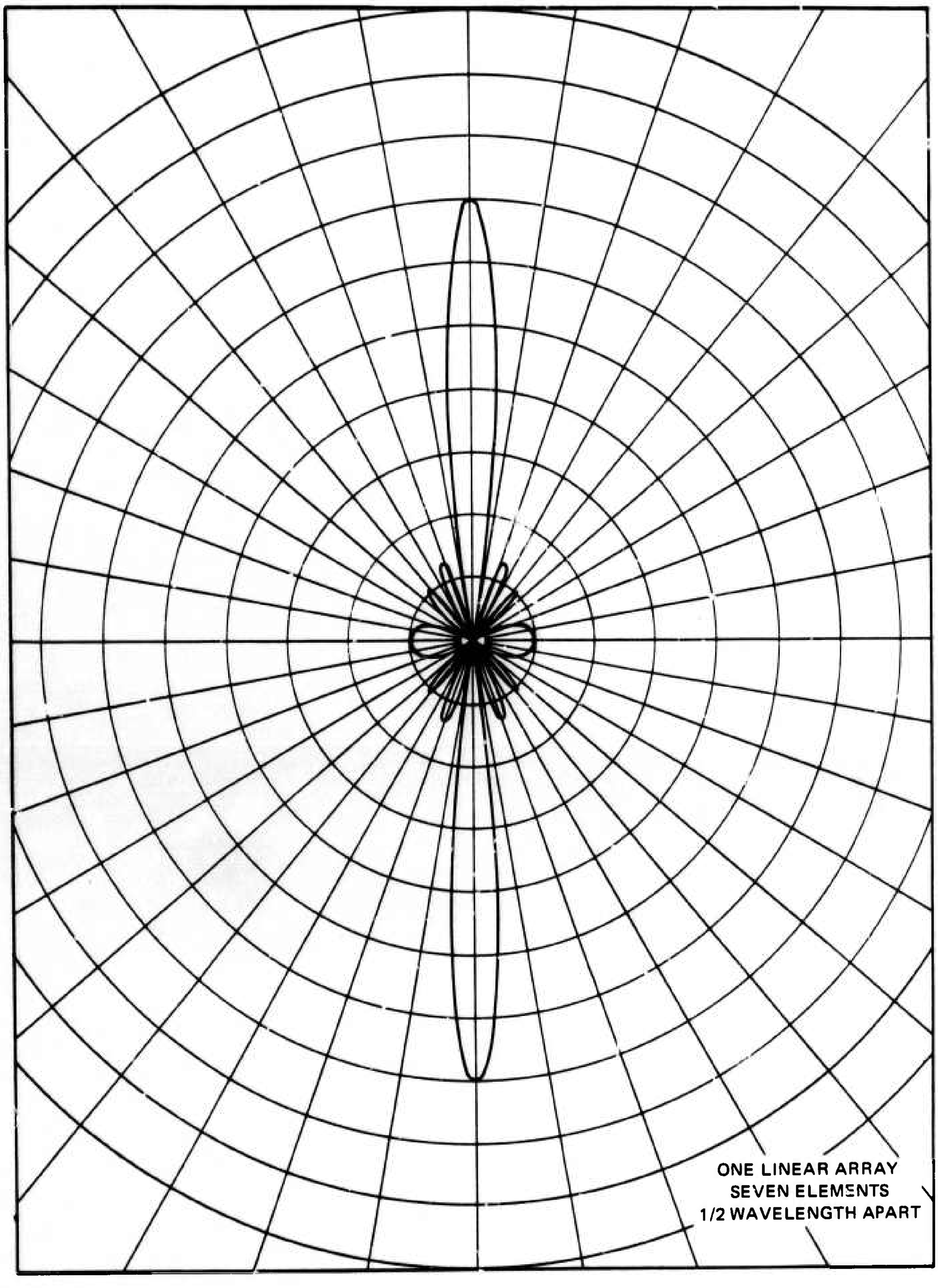


Figure 14. Directivity pattern

G 5537

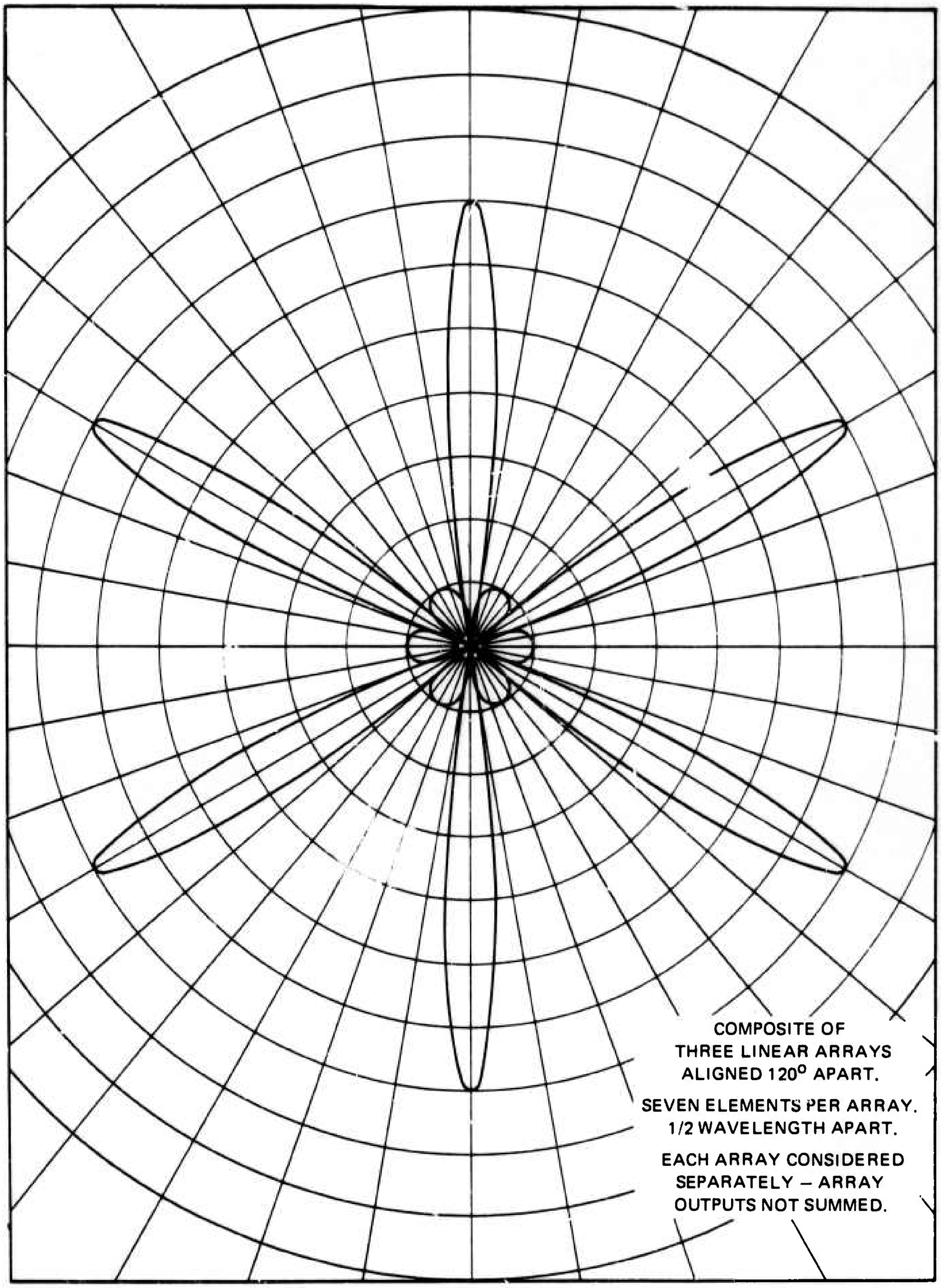


Figure 15. Directivity pattern

G 5538

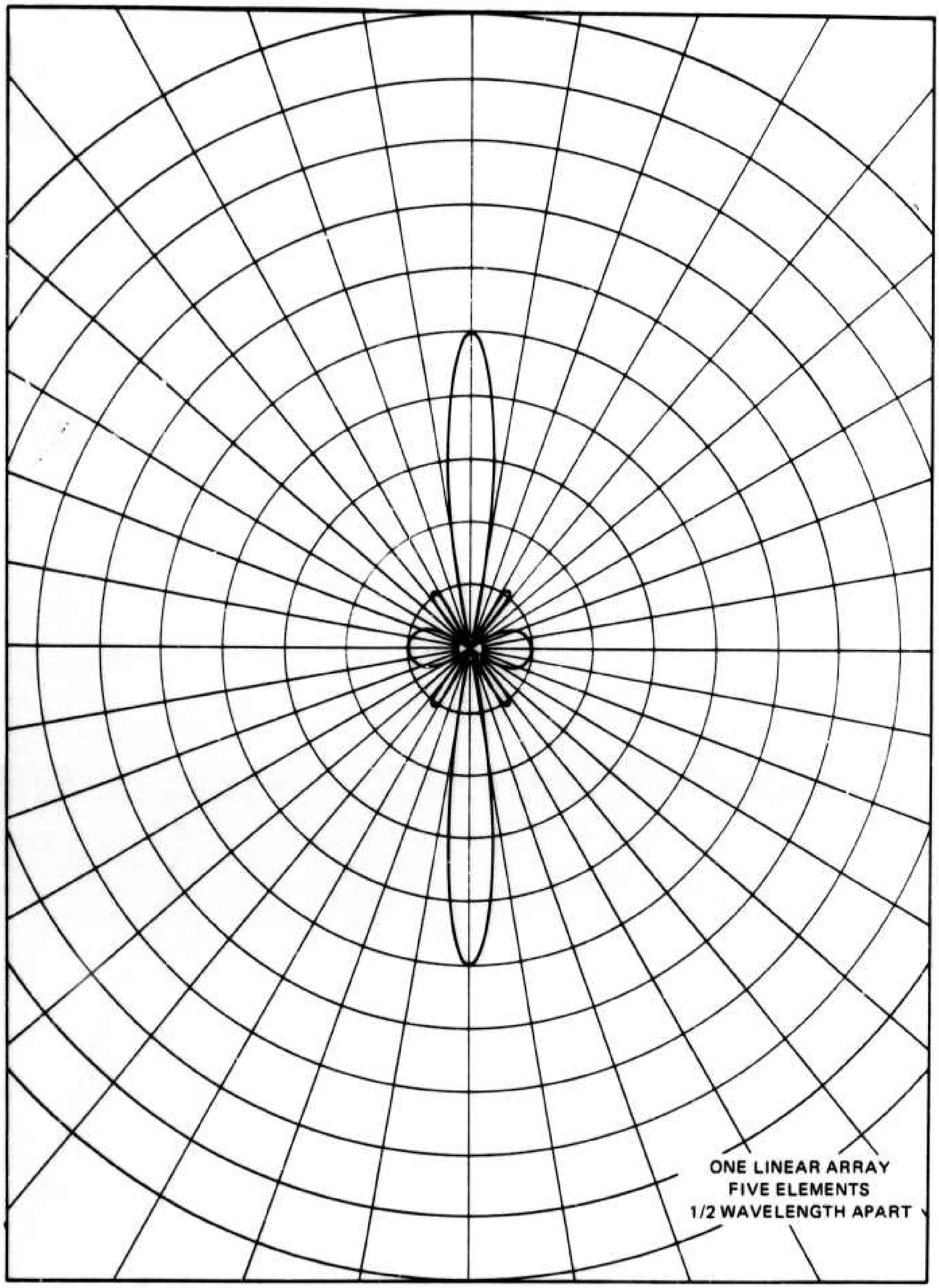


Figure 16. Directivity pattern

G 5539

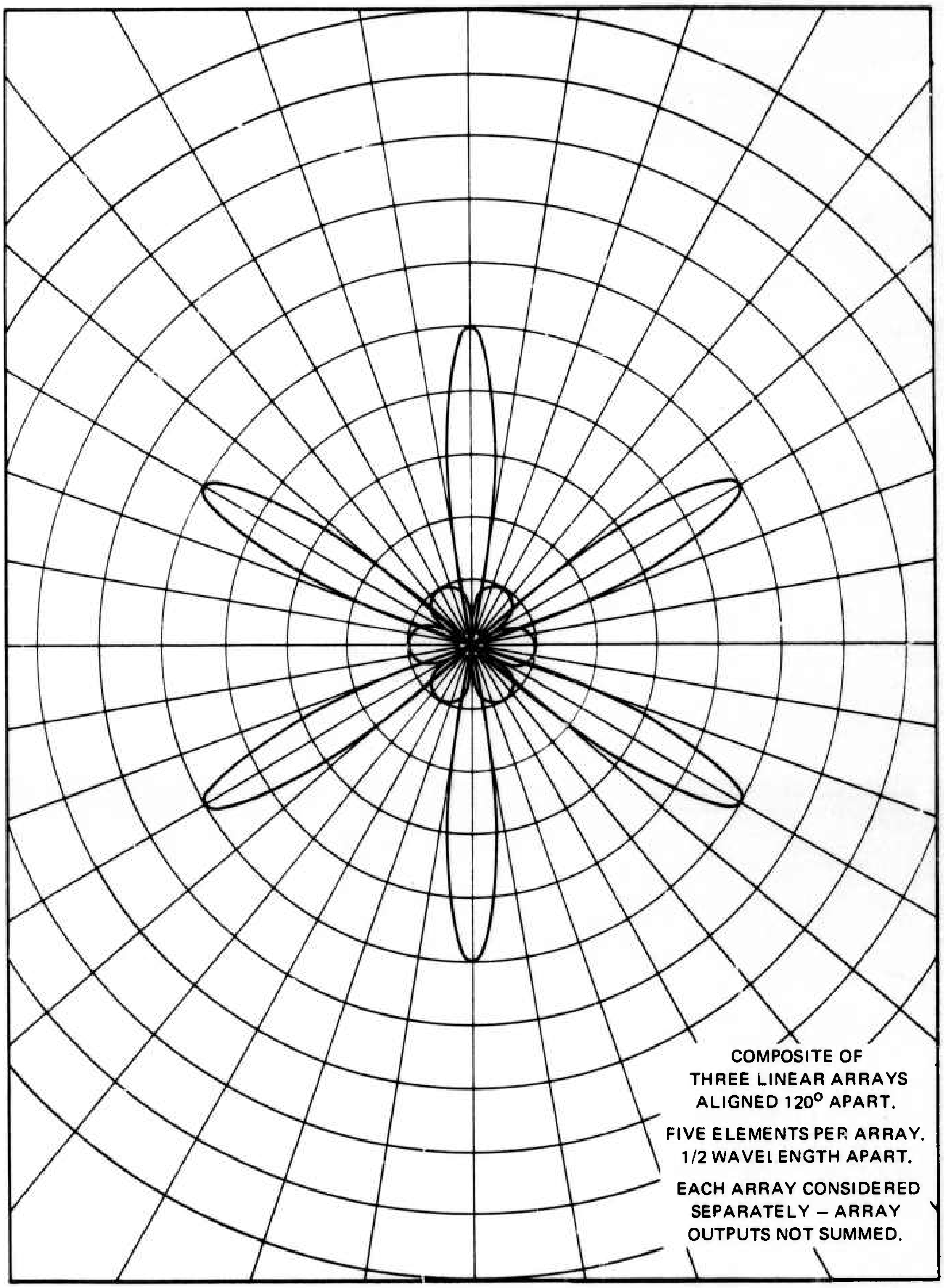


Figure 17. Directivity pattern

G 5540

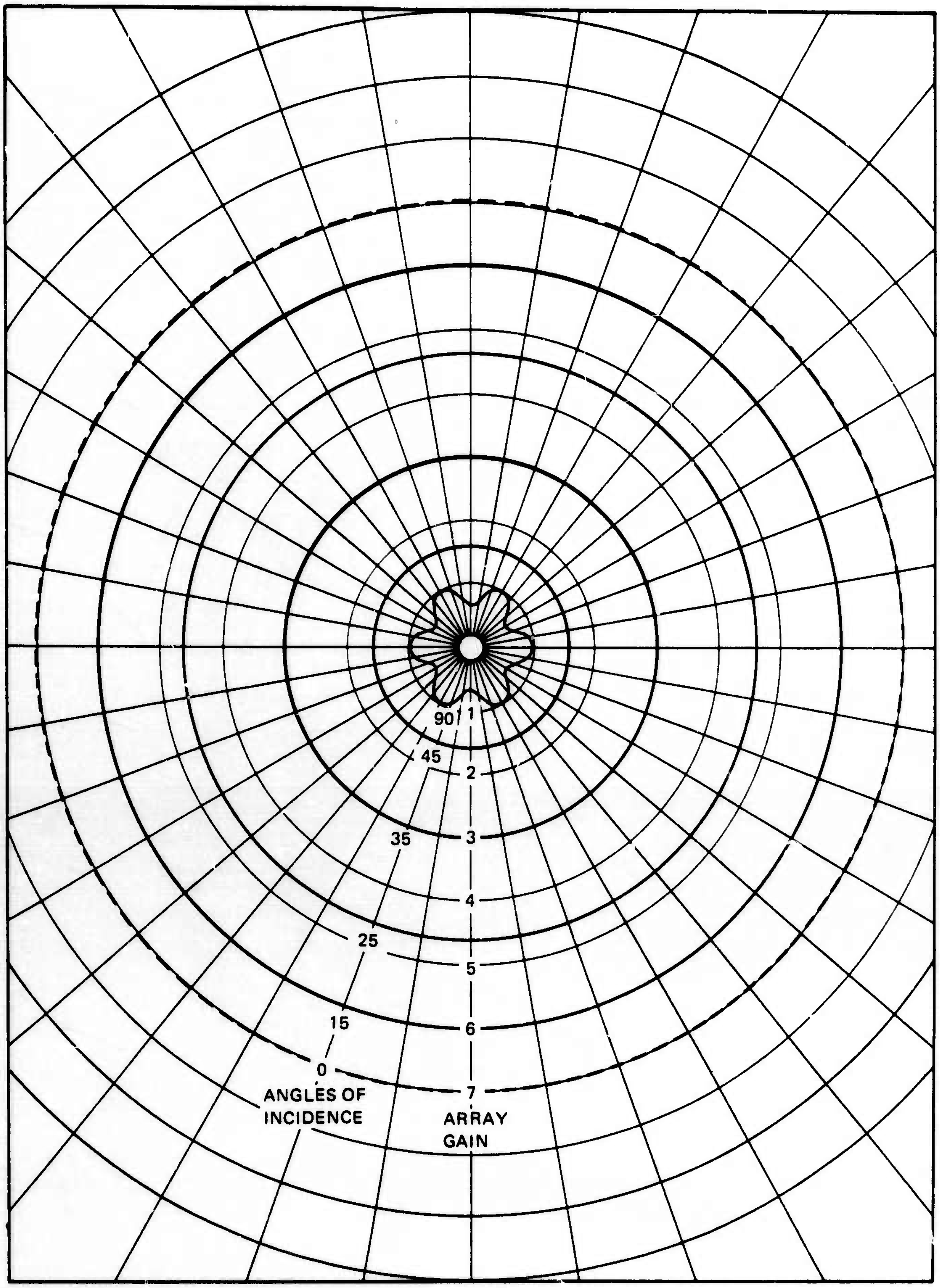
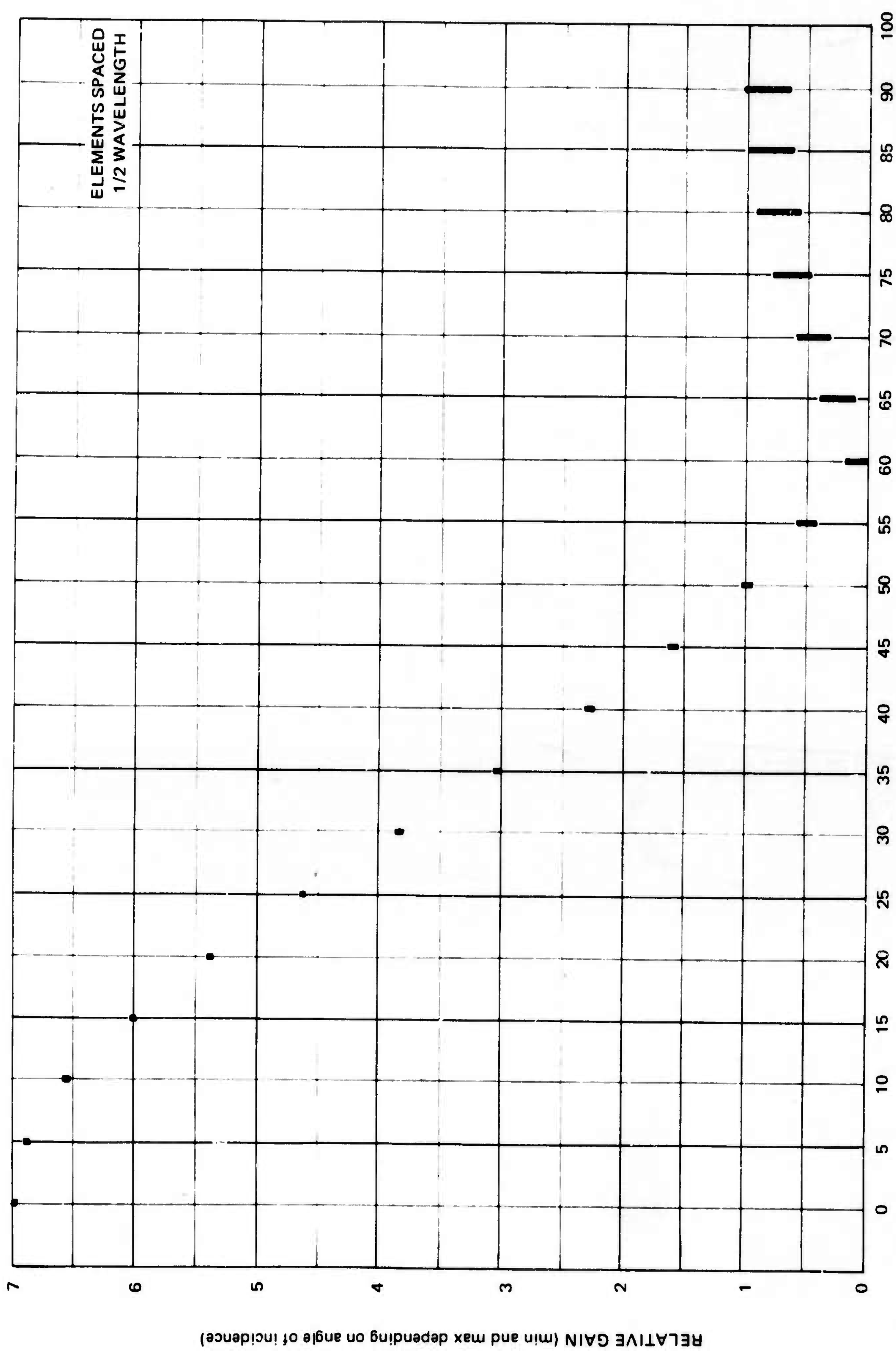


Figure 18. 7-element omnidirectional (spaced 1/2 wavelength)

G 5541



G 5542

Figure 19. 7-element omnidirectional array

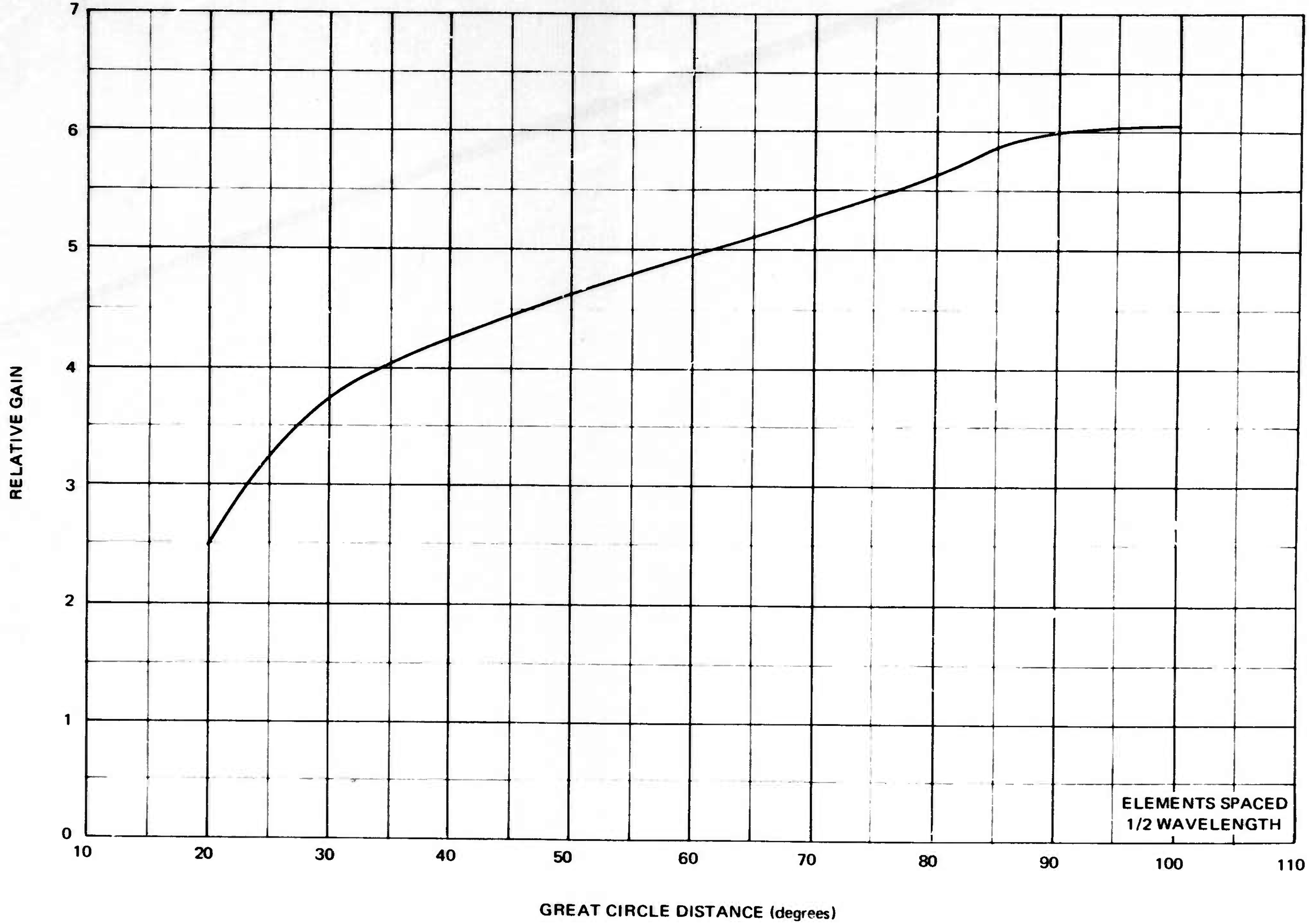


Figure 20. 7-element omnidirectional array

G 5543

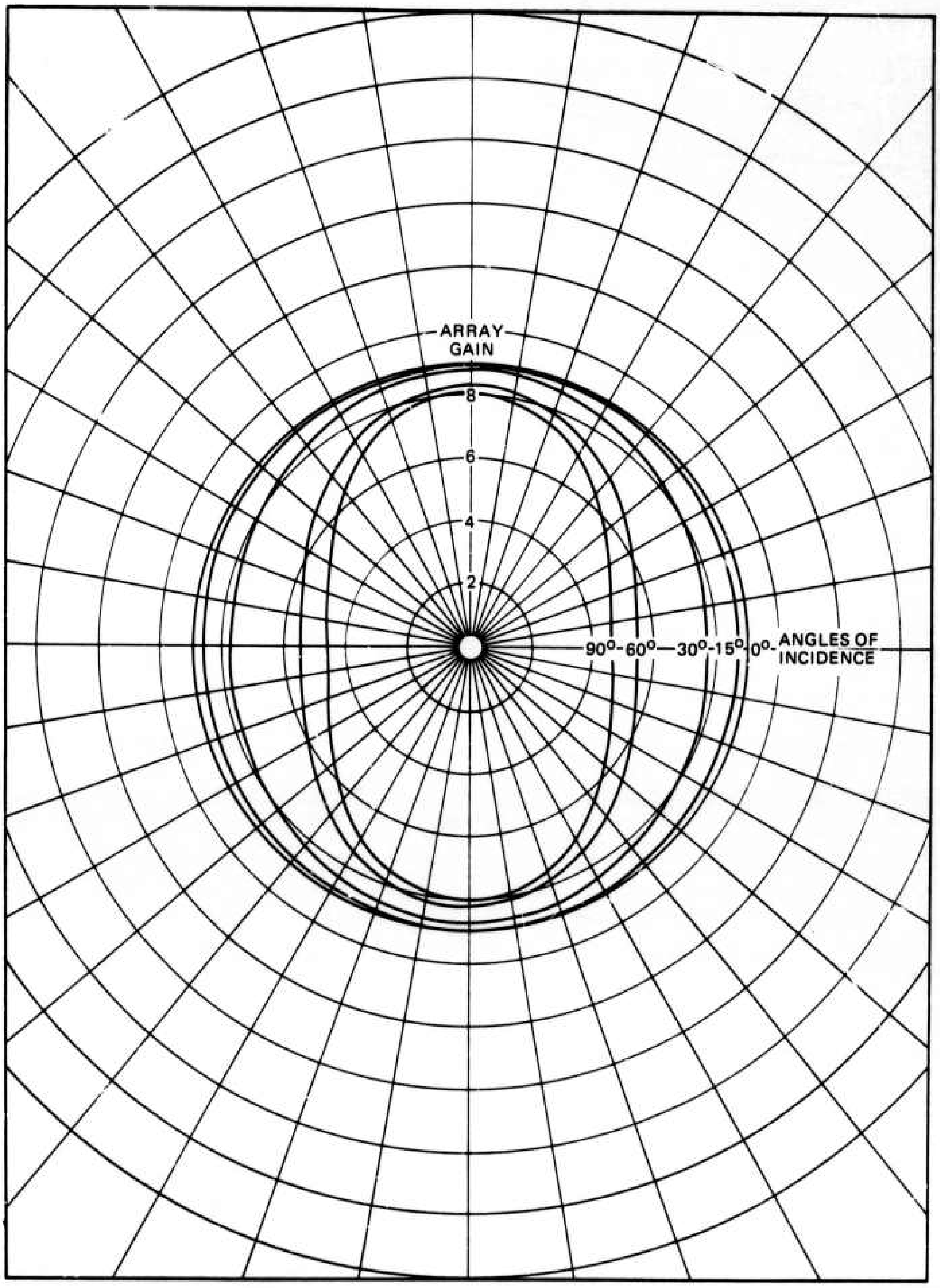


Figure 21. Crossed-linear array

G 5544

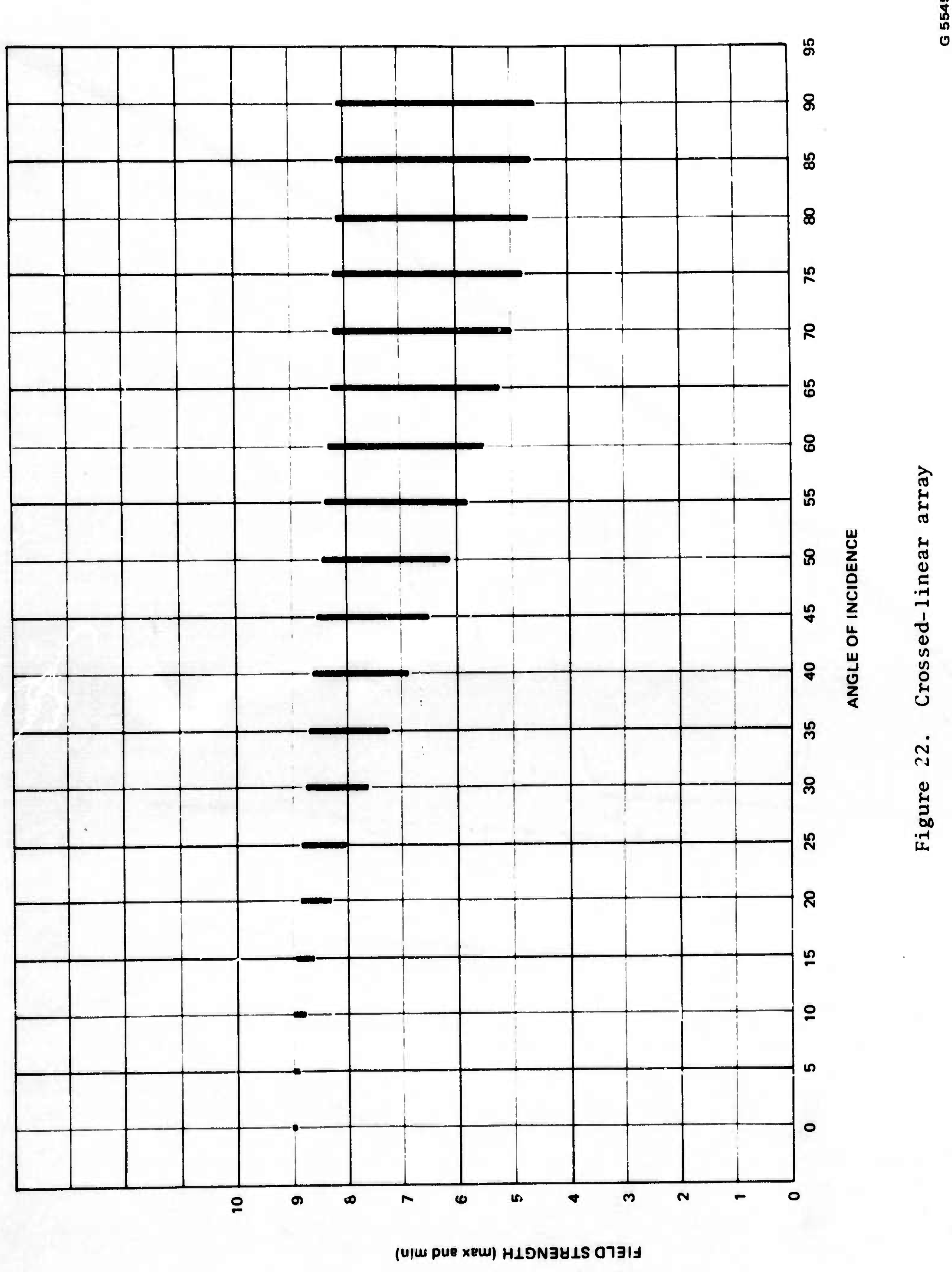


Figure 22. Crossed-linear array

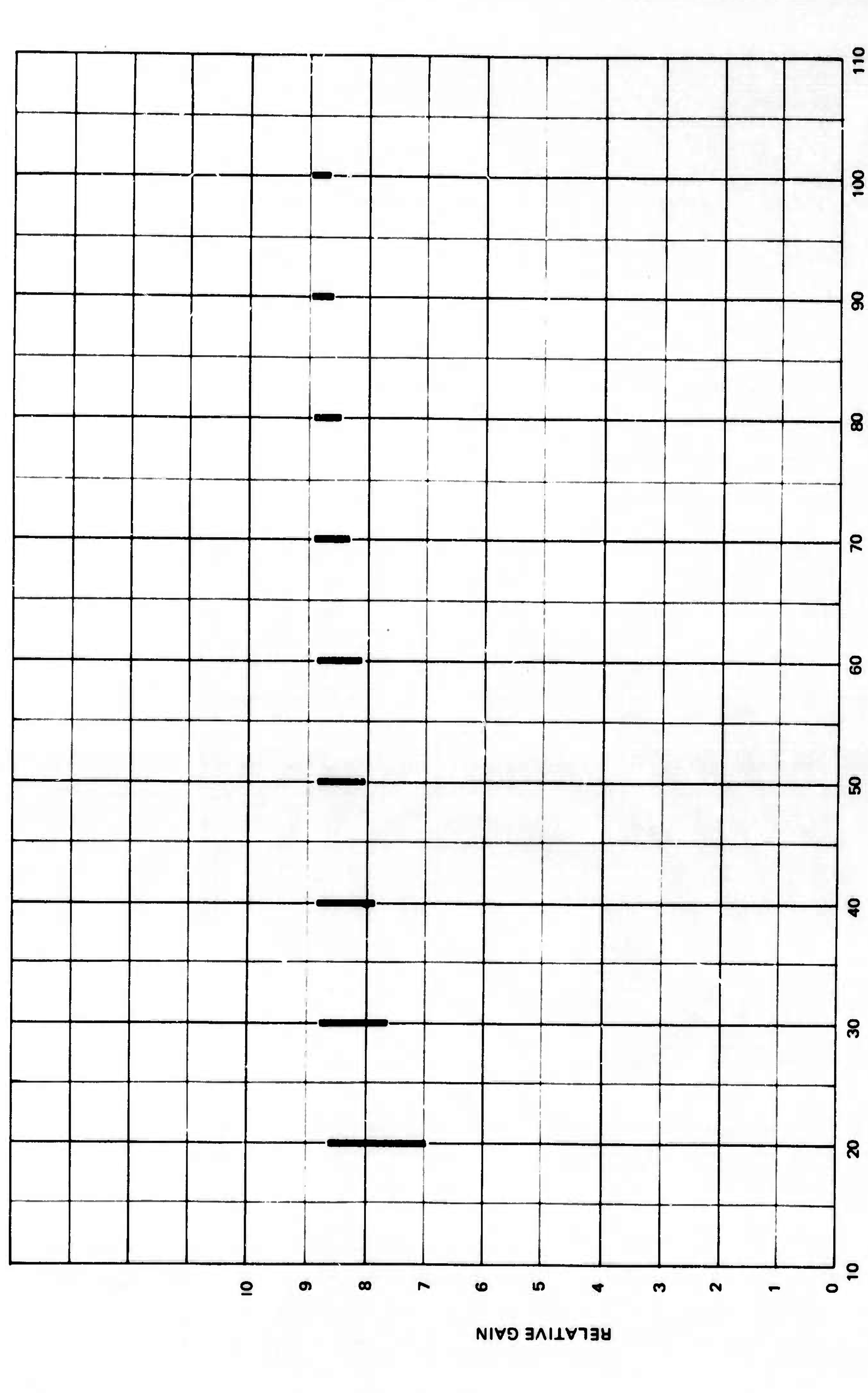


Figure 23. Crossed-linear array

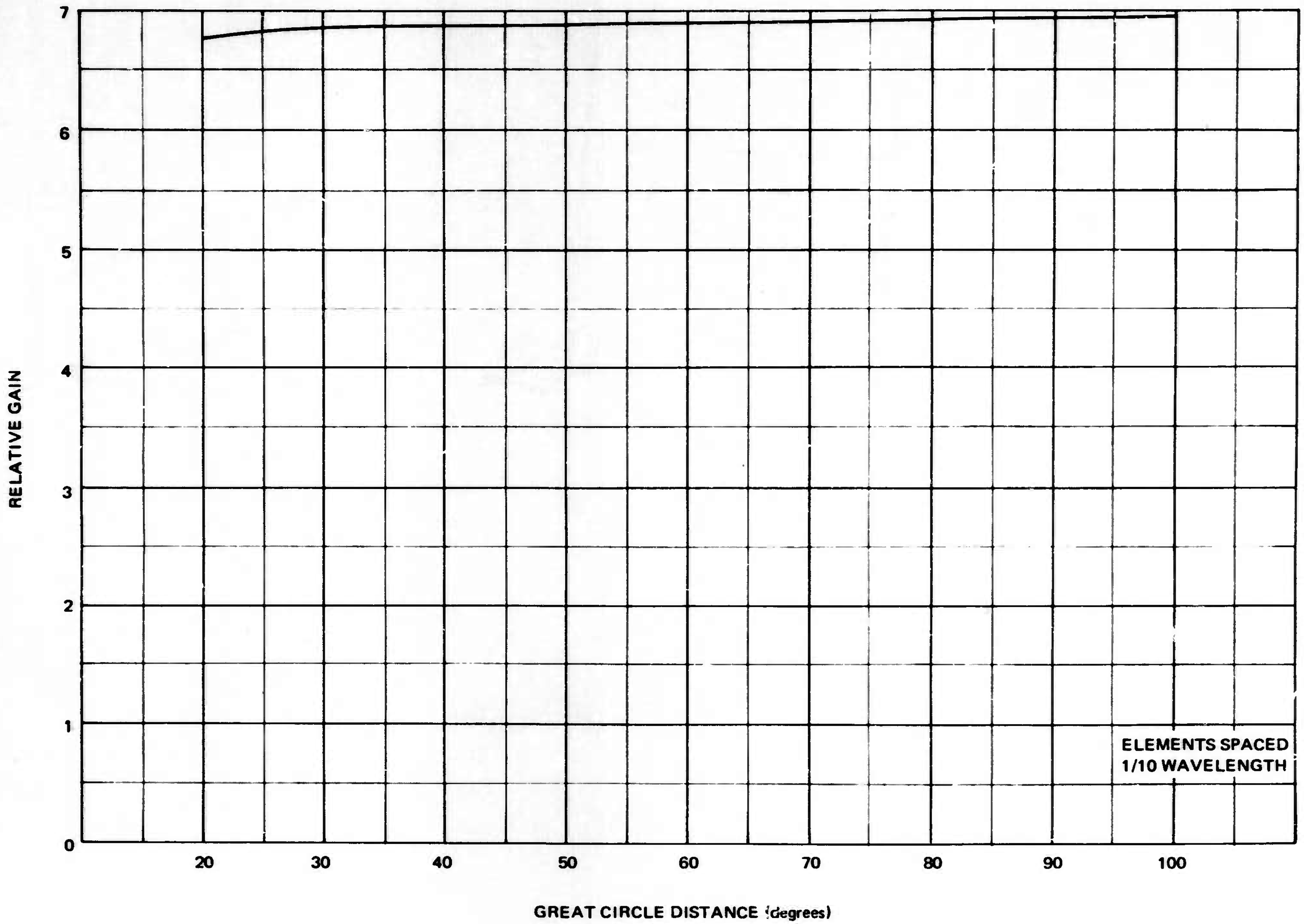


Figure 24. 7-element onnidirectional array

G 5547

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Geotech, A Teledyne Company 3401 Shiloh Road Garland, Texas	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Operation of the Tonto Forest Seismological Observatory
Final Report, Project VT/9702, Contract F33657-69-C-0803
1 January through 31 December 1969

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
Geotech Staff

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 February 1970	114	

8a. CONTRACT OR GRANT NO. F33657-69-C-0803	9a. ORIGINATOR'S REPORT NUMBER(S) TR 70-1
b. PROJECT NO. VELA T/9702 c. ARPA Order No. 624 d. ARPA Program Code No. 6F10	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Chief of AFTAC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency Nuclear Test Detection Office Washington, D.C.

13. ABSTRACT

The report

This is a report of the work accomplished on Project VT/9702 from 1 January through 31 December 1969. Project VT/9702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes special research and test functions carried out at TFSO and research and development tasks performed by the Garland, Texas, staff using TFSO data.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Operation of TFSO						
37-element short-period array						
7-element long-period array						
Multichannel filter						
Lightning protection modifications						
Spiking problems						
Seismograph operating parameters						
Short-period array systems modifications						
Instrument reliability; short-period and long-period array						
Flag traces						

Unclassified

Security Classification